Ruptures: Life without Germs in the Microbiome Era

By

MELISSA ANN WILLS
DISSERTATION

Submitted in partial satisfaction of the requirements for the degree of

DOCTOR OF PHILOSOPHY

in

English

in the

OFFICE OF GRADUATE STUDIES

of the

UNIVERSITY OF CALIFORNIA

DAVIS

Approved:

Colin Milburn, Chair

Kathleen Frederickson

Mark Jerng

Committee in Charge

2021

Abstract

This dissertation examines the legacy of germfree animal research in 21st-century human microbiome science. I show how the scope and diversity of human-associated microorganisms are being revealed through a deep cultural imagination of life in the absence of microbes. Across professional and popular scientific writing as well as fiction, I uncover a pervasive rhetorical maneuver I term *speculative germfreeness*: the imagination of aseptic catastrophe, at the nested scales of individual bodies, societies, and planets, deployed to prompt readers into revaluing the microbes that surround them. Speculative germfreeness is a cornerstone of contemporary microbiome discourse, essential to its claims for the importance of microbiome research in transcending the conventional paradigm of microbial eradication. Chapter 1 surveys the origins of germfree animal research in the late nineteenth century and its first adoption as a speculative device in the fiction of H. G. Wells. The chapter documents the historical imagination of germfree planets and societies in fiction and in popular science and concludes by showing how microbiome scientists and journalists draw on these precedents. Chapter 2 follows the thread of germfree disaster on a smaller scale in examining how fiction and popular science have told stories of bodies, both animal or human, confined to germfree bubbles. I detail how microbiome discourse reworks these narratives as parables for the folly of the antibiotic approach to microbial life. In Chapter 3, I argue that obstetric microbiomics is rewriting the stories of germfree disaster fiction in order to frame birth as a consequential passage between the germfree uterus and the germy planet. The chapter suggests that these rewritings cast mothers as singularly responsible for seeding their children's nascent microbiomes and also burden them with the obligation to mother the microbial planet itself. Finally, Chapter 4 demonstrates how microbiome research, in its recent shift to translational metagenomics, has moved away from earlier themes of germfree disaster by developing novel metaphors of human-bacterial conversation. I

argue that the ideal of speaking with one's microbiome loosens the strictures of germfree obligation by establishing bacteria as agential participants in a conscientious human-microbial partnership.

Acknowledgements

My gratitudes, like my microbiome, are multiple. I first want to recognize Colin Milburn, who nurtured the first sparks of this dissertation and who has steadfastly believed in my ideas through the long years of research and writing. I also recognize my committee members Kathleen Frederickson and Mark Jerng, who have nurtured my growth as a scholar and a person throughout the process. I am indebted to Jim Griesemer and Hsuan Hsu for serving on my qualifying exam committee, as well as to Con Diaz for helping me to conceptualize the project's historical focus.

This document comprises tokens of an educational career spent in, and between, two worlds. Eric Harvill supported my undergraduate research in bacteriology; Blossom Damania taught me the finer points of virology research while also granting me time to explore my fledgling literary interests. John Morillo, Carmine Prioli, Kathy Psomiades, and Joseph Viscomi coached me through the challenges of learning a new field as a graduate student and made my transition to doctoral work possible.

I am grateful for the many institutions that have supported my dissertation work. Generous grants from the Bilinski Foundation, Davis Humanities Institute, Department of English, and the University of California Humanities Research Institute have supported my research and writing. To the Eaton Collection of Science Fiction & Fantasy at UC Riverside, the Center for the History of Microbiology/American Society for Microbiology Archives, and the National Museum of American History's Archives Center I owe the pleasure of getting lost in my primary sources. I am particularly grateful to Gan Haverim Preschool, Millennium Child Development Center, and Davis Joint Unified School District for safeguarding my children so that I could learn, write, think, and teach; and to the UCD Student Parent Child Care Grant Program for subsidizing the costs of their care.

Many friends and scholars have sustained me along the way. My thinking on microbes and microbiomes have been shaped by exuberant conversations with Andrew Inkpen, Stephanie Maroney, Andy Murray, Tami Schneider, Kym Weed, and the many undergraduate students who have gamely agreed to join me in my obsessions. For helping me to grow as a scholar, a parent, and a human, I thank my dear friends Renee Bryzik, Katherine Buse, Jordan Carroll, Beth Foraker, Holly Gallagher, Kalista Hickman, Katie Leveling, Rilla Nelson, Josef Nguyen, Sara Petrosillo, and Leslie and Eugene Rubin.

None of this would have been possible without my family. My parents, John and Becky Wills, showed me from an early age that science is exciting; the seeds of this project were first planted as I tagged along in their lab as a young child, but their unwavering love through the many twists and turns of my educational trajectory have been what sustained it. My sister, Marci Wills, inspires me daily with her strength and has been my biggest fan since day one. My in-laws, the Schutt and Ashcraft families, have kept the hurdles in perspective and a smile on my face. Above all I am grateful for the love and support of my husband, Jeff Schutt, who believed in me before I did; and our two children, Jonah and Colin Schutt, who gestated and grew alongside this project and whose imprint is felt in every word.

Table of Contents

Introduction

It is often said that the human body is vastly outnumbered. Ten microbial cells crowd every human cell; a hundred microbial genes counter each human one.[1] For much of the past century and a half, these numbers would have summoned visions of infection, disease, and death. In the early 21st century, however, the fact that the human body is engulfed in a sea of microbes is consistently relayed to the opposite effect. As contemporary scientists have unveiled the scope and diversity of microbial life associated with the healthy human body—the human microbiome—the familiar idea that microbes are a scourge to be eliminated at all costs has come into question. The idea that we are, quantitatively, less human than microbe has been deployed to startle audiences into confronting not only the fact of our biological constitution but also the prevailing metaphors, biases, and narratives of microbial hostility.

Consider a representative instance from the early days of the public microbiome, a short animated video produced for NPR and illustrated by Benjamin Arthur in 2013, titled "The Invisible Universe of the Human Microbiome." It opens on a silhouetted man loping into view, arriving at a mirror, and studying his reflection. Journalist Rob Stein narrates, "the next time you look in the mirror, think about this: in many ways, you're more microbe than human" (Arthur and Stein). As the man peers into the glass, microbes begin to appear on his surface, drawn as small colored dots. He leans curiously into his reflection, then looks down at his body and steps backward in contemplative surprise (Figure 1).

[1] Though newly prevalent in the time of the microbiome, the 10:1 figure is not new. Microbiologist Dwayne Savage first attempted calculations of the human-bacteria cell ratio in a 1977 paper, writing that "the normal human organism can be said to be composed of over 10^4 cells, of which only about 10% are animal cells" (107). However, the idea that human bodies are awash in microbes is much older. Antoni van Leeuwenhoek had first glimpsed the microbes abounding in human skin, dental plaque, and more (Leeuwenhoek). In 1901, Élie Metchnikoff undertook a site-by-site survey of the microbes dwelling on the human body. And by the mid-20th century, Theodor Rosebury's extensive catalogue of the "microbes indigenous to man" formed an essential codification of this dogma, and was widely read by the generation of microbiologists conceptualizing microbiomics.

Figure 1. Silhouette Man meets his microbes (Arthur and Stein).

Arthur's Silhouette Man was a proxy for American society as a whole in 2013 as microbiome research prompted a collective surprise at the vast scope and variety of microorganisms living in and on our bodies. Across science, journalism, and other media forms, audiences recognized that this knowledge contradicted conventional understandings of microbial life. The NPR video encapsulates the older view in its protagonist's reaction to his microbial constitution. Stein observes that the 10:1 statistic "might make a lot of people rush for the hand sanitizer." The man hurries to brush his microbes off, leaving them in a heap on the ground. He then takes off walking toward a gray and smoggy city landscape—a space where he will presumably be safer from microbial threats.

He is not alone on this journey: his progress from unknowing host to microbial void allegorizes a multigenerational Western trajectory toward asepsis, characterized by microbiome discourse as an obsession with germ eradication at the expense of bodily health. The impulse to shake off the microbes reflects the heritage of the germ theory of disease as developed by Louis Pasteur, Robert Koch, and Joseph Lister in the late 19th century, with its central insight that infectious diseases are traceable to microbial invasions of the human body.[2] Through texts equating

[2] On the development of germ theory, see Tomes, *The Gospel of Germs* and Worboys, *Spreading Germs*. Both caution that germ theory did not mark a decisive shift, nor was it a singular comprehensive theory. For purposes of this project, I use the term "germ theory" to refer to the complex, plural conceptions of microbial-borne illness to which the discourses I study respond.

pathogenic bacteria with human enemies and racialized or gendered others,[3] through narratives of heroic bacteriologists locked into battle with microbial threats[4], and through an onslaught of public health messaging, advertising, and fiction,[5] Americans learned to fear germs—to flinch, as Silhouette Man does, when confronted with even the benevolent microbes occupying our skin. Germ fears reached a peak with the rise of emerging infections in the 20th century, from AIDS to Ebola, evidenced in the proliferation of outbreak narratives and bioterrorism fiction that sharpened the perception that society—even humanity itself—risked destruction by microbial intruders. Meanwhile, rising antibiotic resistance seemed poised to undo modern healthcare entirely. As Brigitte Nerlich has noted, the result of these events has culminated in a recurrent "catastrophe discourse" spanning both microbiology and healthcare, and which forms the immediate backdrop to microbiome discourse's claims of microbial precarity (574).

In the NPR video, this traditional approach to microbes is recharacterized as an overly aggressive defense against infection that threatens the microbiome and thus human health. As Silhouette Man walks toward the city, his gait changes to a shuffle. He slouches, then holds his head in a hand before collapsing in a heap (Figure 2). His condition has been brought about by his personal effort to remove the germs. Stein says, "it turns out most of these microorganisms aren't bad germs that will make us sick. Most are good. And without these good microbes, our bodies don't seem to do as well. We don't seem to be to be as healthy. And we actually might get sick more

[3] On microbiological SF as overlaying gendered and racist thinking onto bacteria, see (Bollinger), (Diehl), and (Schell).
[4] Foundational examples include Lewis Sinclair's *Arrowsmith* and Paul de Kruif's *Microbe Hunters,* which inspired generations of microbiologists.
[5] E.g., (Tomes 2002) and (Tomes 1998) for discussion of microbes in public health and entertainment. On the legacy of outbreak fiction in American culture, see Wald, *Contagious*. For discussion of the post-9/11 discursive landscape that co-emerged with the microbiome, see (Cooper) on how germ warfare threats influenced U.S. public health and foreign policy, and Thomas, *Training for Catastrophe* on bioterrorism themes in fiction.

often." At that last bit, Silhouette Man coughs and collapses, arms reaching helplessly toward his discarded pile of germs—yearning for wholeness, too late.

Figure 2. A newly unmicrobed Silhouette Man goes to the city (Arthur and Stein).

This image of the wrecked germfree body is not unique; in fact, it resounds across microbiome discourse. Continually reinvented as a figure for the toll of attempting to live without our accustomed microbes, the germfree body symbolizes *antibiosis*—the philosophy of microbial extermination—with consequences to body, mind, and society. The speculatively germfree human body persists in microbiome discourse particularly through tropes and narratives of imagined human futures lived catastrophically without germs. In this project, I trace the historical emergence of speculative germfreeness as it has arisen from the material legacy of laboratory animal research and the imaginative legacy of germfree disaster narratives, which have been entwined in the public imagination since the origins of microbiology and science fiction in the late nineteenth century. I follow the aphorisms, images, tropes, and narratives of germfree life as they have manifest across scientific and cultural texts ever since. These form a rhetorical cornerstone of microbiome discourse as the journalists and scientists of today recurrently turn to the speculatively germfree human body in order to advance claims about the folly of overlooking our microbial symbionts and the importance of leading microbially-conscious lives. The imagined disaster of life without germs, at once terrifying and familiar, pervades because it frames microbiome science as a heroic intervention in a culture that dreams of a world without disease.

This cultural work is evident in the plight of NPR's Silhouette Man, who comes to signify the consequences of attempting to transcend microbes not only for an individual, but also for human society and the planet itself. "The Invisible Universe" suggests that germophobia impacts more than an individual's body. In a point echoed widely across early microbiome discourse, it implicates overzealous antiseptic practices in the devastation of the wider microbial ecosystems in which we live, and which have arisen from the quasi-religious fervor with which Americans have shaped their daily practices so as to redeem themselves from infection (Tomes 1998). The urban landscape is just as depleted as the protagonist's body: this city, shrouded in smog, deserted and ghostly, is a victim of the cultural impulse to do away with germs. In the video's progression from green to gray, rural to urban, germy to sterile is encoded the argument that modernity itself poses a threat to the microbially whole human body. Silhouette Man's ultimate collapse amidst the city smog indicates a belated recognition that the sequelae of germfree aspiration are perhaps more devastating for both body and planet than is infectious disease. Microbeless and defeated amidst a toxic urban landscape, he encapsulates the microbiome-era sentiment that we simply can't do without our germs, but we are dying in the effort.

Through the de-germing and suffering of their protagonist, Arthur and Stein set forth the argument that an understanding of the body as thoroughly microbial necessitates a reckoning with the consequences of conventional approaches to the microscopic world. Through glimpsing the devastations of a body and environment without germs, audiences are led to identify the value of microbial contributions. Indeed, Silhouette Man's progress from unwitting germiness to aspirational sterility signals the foundational assumptions that his creators, and microbiome discourse as a whole, wished to challenge. Variations on the theme were replicated elsewhere, everywhere across science and popular culture in the early 2010s; the threat of germfree disaster as a spur to microbial

appreciation is a core component of the microbiome-era assertion that we cannot do without our microbes. The imagination of germfree bodies, enclosures, and worlds everywhere asserts that people ought better to value the microbes with which they live. It is a means of summoning and negating latent germophobias and redirecting audiences to go forth and live new, microbially-conscious lives.

The microbiome, in fact, stands to save humanity from its aspirational asepsis. Again and again in microbiome discourse, the depleted modern body is rescued by the novel recognition of humanity's microbial nature. In the NPR video, Stein's narration cuts away from the urban journey to introduce viewers to the human microbiome concept. The video then launches into an extended introduction to the human microbiome, illustrated by charming immune cells and cute babies. In short order it acquaints viewers with the origin of an individual's microbiome (mom, in the birth canal), the threats posed by antibiotics and overzealous cleaning, associations with noncommunicable diseases, and the hope for probiotic therapy.

As the video draws to a close, Silhouette Man pops back into view apparently revitalized by this extended discussion of microbial necessity. Having dragged himself back to his pile of discarded microbes, he reaches a weakened arm forward as Stein says, "it's getting clearer and clearer that the tiny organisms all over our bodies are essential to our health and happiness." The pile disperses on contact, swirling into a cloud that fills the screen. Within, germfree man is resurrected, drawn into a triumphal pose while microbes spiral around him (Figure 3). Reborn, he glances down at his body once more, this time flexing his arms: he now understands that microbes are his strength. The microbiome, and his recognition of its now-visible presence in his body, has rescued him from the sins of modernity.

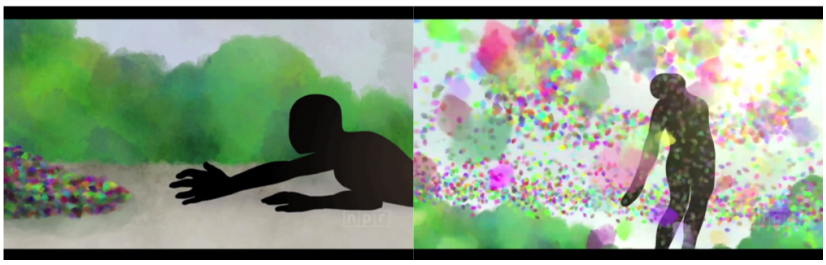

Figure 3. Silhouette Man, reborn as microbial being (Arthur and Stein).

The video narrates a triumph of ecology and microbial acceptance over the prevailing conditions of antisepsis, one that is meant to prompt audiences to reach for their own microbes so that they too might be resurrected as *homo microbis:* as a "microbial human" constituted by, and cognizant of, the microbes within (Helmreich 62). It is a shift driven by the video's turn to the spectacle of a catastrophically germfree body and landscape. It would seem that simply reciting the facts of microbiome research is not enough to impress upon viewers the necessity of their microbes. Rather, it is the witnessing of a hapless Everyman's journey from disbelief and horror to acceptance that enables a confrontation with the exterminative impulses of antibiosis. "The Invisible Universe" therefore asserts the power of germfree speculation to shape public opinions and practices surrounding the microbiome. In its various manifestations across microbiome discourse, the plight of the germfree body is invoked as a means of revealing antimicrobial biases and transmuting them into an appreciation of microbial presence.

1. Microbiome Beginnings

At the turn of the 21st century, there was growing scientific consensus that a greater attention was needed to human-microbial ecology. The period of relative complacency regarding microbial threats that had marked the golden age of antibiotics had been shattered by the arrival of HIV/AIDS and the growing recognition of the threat posed by global emerging diseases such as hantavirus, Ebola, and avian flu. Disease fears were deepened by the accelerating pace of

antimicrobial resistance. At the same time, it was becoming clear that the conventional approach of linking diseases to single invading organisms was out of date: maladies such as gastric ulcers, Lyme disease, and liver cancer had recently been linked to microbial origins. Scientists were also learning that not all pathogenic organisms were always pathogenic and that the onset of disease might be influenced by events in the immune system or the context within microbial communities in the body.[6]

With this "litany of wake-up calls" (Lederberg, "Infectious History" p. 290), it seemed clear that greater attention was needed to the communities of microbes within the human body. New molecular sequencing tools were enabling the detection of microorganisms that could not otherwise be cultivated outside of the body, and research was showing the scope of the human-associated microflora to be more expansive than previously recognized.[7] Meanwhile, research into germfree animals was revealing that the microflora not only inhabited the body but actually shaped it. The development of the mammalian gut, for instance, was incomplete in the absence of microbes.[8]

In response to this growing sense of microbial peril and promise, researchers in microbiology, genomics, and ecology united to envision a form of scientific microbiome inquiry that would lay outside of the agendas of human infectious disease biology. In a series of conferences, workshops, and opinion articles, they together established a framework for investigating the microbial ecology of the human body. Their efforts aggregated around the term *microbiome*, a neologism attributed to bacterial geneticist Joshua Lederberg. While the word "microbiome" had historically surfaced on occasion to refer to a *micro-biome*, that is, a tiny biome or ecological space not

[6] For instance, (Casadevall and Pirofski 1999) argued for a comprehensive redefinition of the concepts of pathogenicity and virulence in order to include the contributions of both pathogen and host to the progression of disease.
[7] E.g., (Bäckhed et al. 2005).
[8] See (Hooper and Gordon) on the development of the mammalian gut and (Falk et al.) for a foundational review of germfree animal research and gut ecology influential on the microbiome concept.

confined to the human body, Lederberg's coinage defined *microbiome* as both an ecological and a genetic entity (Eisen, "What Does the Term Microbiome Mean?"). In an early formulation, he described the microbiome as "the DNA descriptions of all species of natural flora and parasites—both beneficial and pathological—that attend our being—both interior and exterior" (Lederberg and et al.). In other words, the microbiome concept refers to the DNA sequences of the ecological components of the human body. Etymologically, as Lederberg observed elsewhere, the term merges the ecological concept of the *biome* with the prefix *'ome—,* meaning "all" (Lederberg, "'Ome Sweet 'Omics"). It thus means everything—all of one's critters—as detected through their DNA sequences.[9] In this project, I draw on Lederberg's concept and the usage that has followed, using the term "microbiota" to refer to the organisms living in and on the human body, and "microbiome" in the genomic sense as the collective DNA sequences as envisioned by Lederberg.

A convergence with human genomics afforded a crucial opportunity for Lederberg and colleagues, who increasingly advocated for a large-scale sequencing initiative of the human microbiome. The first draft of the human genome had just been published; they proposed a massive sequencing project to survey the microbiota of the human body as revealed by the sequencing tools and ethical framework of the Human Genome Project.[10] This they conceived of as a "second human genome project" (Relman and Falkow), a mission of self-discovery on a grand scale. But where the HGP had centered rhetorically around the idea of reading or deciphering the book of life, this new post-genomic initiative promised something more dynamic, investigating a self that was now understood to be "plural and fluid," contingent on the properties of one's attendant microorganisms

[9] Phylogenomicist Jonathan Eisen expressed discomfort with this choice of terminology in part because of the proliferation of 'ome words at the time of Lederberg's coinage. He suggests that the proliferation of the "ome-meme" is "a form of the overselling of genomics" leading to unnecessary hype (2012 p. 2).

[10] The HMP genesis was marked by a deliberate expansion of the HGP's approach to ethical, legal, and social concerns, most visibly as outlined in the HMP working group's volume published in 2013 (Rhodes et al.).

(Nerlich and Hellsten 13).[11] The Human Microbiome Project, which was launched in December 2007, announced itself as an investigation of human identity. Its logo featured a silhouette of Leonardo da Vinci's Vitruvian Man, arms and legs spread wide and encircled by a double ring signifying the phylogenomic analysis of bacterial family trees (Figure 4). The graphic suggests a theme that would dominate the microbiome in popular culture: the human body is surrounded and defined by its microbial contingent.

Figure 4. Human Microbiome Project logo, defining the human with reference to the phylogenomic map surrounding it.

The Human Microbiome Project was not the only large-scale sequencing initiative to be developed in the early 21st century, but it was certainly the most prominent effort in the United States. Officially, it was a five-year, $173 million undertaking carried out by 200 researchers across almost 80 institutions. The project aimed to conduct metagenomic analysis on samples from five body sites in 242 healthy individuals, combined with whole-genome sequencing of select isolated organisms. It was envisioned as a first step, a means of building a repository of information and reference genomes that would guide future research. Methodologically, it drew upon pioneering technologies of metagenomic sequencing first developed within the field of environmental microbiology,[12] using fragments of genomes and reassembling them like puzzle pieces to reconstruct

[11] On the situation of microbiome research within the larger ecosystem of postgenomics, see (Richardson and Stevens).
[12] The National Research Council's Committee on Metagenomics influentially described the methods and tools of metagenomics as pertaining to the study of the human microbiome (National Research Council). The HMP's own

whole genomes of environmental microbes. In the context of the human body under study in the HMP, this meant a finer-grained analysis, more precise time points, and a more detailed assessment of the species present at a given moment than had ever been achieved previously. Practically speaking, it meant the ability to detect microbial strains without the requirement of culturing them *ex vivo* in the laboratory, dramatically expanding the census of known associates on the human body.

In June 2012, the HMP's first results were published in a coordinated, open-access block and accompanied by an intensive public relations apparatus comprised of press releases, telebriefings, scientific commentaries, and sponsored science journalism.[13] These together narrated the dawn of a new era and celebrated the novel vision of microbial plenitude. As one HMP researcher based at the Marine Biology Lab in Woods Hole, MA explained in an interview published in coordination with the June 2012 release, "The more closely we look, the more bacterial diversity we find… We can't even name all these kinds of bacteria we are discovering in human and environmental habitats. It's like trying to name all the stars" ("More than One Way to Be Healthy"). Another release published the same day at Washington University in St. Louis, an HMP research site, opened by foregrounding microbial diversity specifically as coterminous with the human body in an invisible profusion: "Trillions of microbes inhabit the human body, occupying virtually every nook and cranny. And most of the time, this relationship is a friendly one, with microbes helping to digest food, strengthen the immune system and ward off dangerous pathogens" (Arbanas).

These first communications met an eager audience. After decades of outbreak narratives and germ theory, the idea that bacteria might colonize the human host benevolently—might even

statement of its intervention, methods, and significance was published with the first round of research publications in (Turnbaugh et al. 2007).

[13] Results of the initial HMP studies were published in multiple *Public Library of Science* journals (collected at https://www.ploscollections.org/hmp), alongside two overview articles by the Human Microbiome Project Consortium in the 13 June 2012 issue of *Nature*.

contribute to health and physiological functioning, co-constituting it rather than simply invading it—was a novelty. It seemed as though public conceptions of microorganisms and their relations to human physiology were transformed nearly overnight. In an avalanche of books, journalism, and marketing hype that were frenzied in their energy and optimism, the microbiome went mainstream.

In the public domain, the sudden and public revelation of microbial life's plenitude was frequently expressed as revolutionizing humanity's sense of self-identity, in alignment with the HMP's rhetorical precedent. The theme was often presented as a shift in scalar perspective. "I know the exact date," wrote Michael Pollan in a 2013 article for *New York Times Magazine*, "that I began to think of myself in the first person plural—as a superorganism, that is, rather than a plain old individual human being." The date in question marked the arrival of his microbiome sequencing results, delineating "the genes not of 'me,' exactly, but of the several hundred microbial species with whom I share this body." Pollan's muddled sense of identity was echoed everywhere. An article published in *The Economist* later that summer, titled "Me, myself, us," led by asking,

> What's a man? Or, indeed, a woman? Biologically, the answer might seem obvious. A human being is an individual who has grown from a fertilised egg which contained genes from both father and mother. A growing band of biologists, however, think this definition incomplete. They see people not just as individuals, but also as ecosystems. ("Me, Myself, Us")

The microbiome, it seemed, upended everything we thought we knew about the basics of bodily boundaries and species lines. In their study of microbiome journalism from 2003 onward, Brigitte Nerlich and Iina Hellsten show how early public descriptions of the microbiome collectively used wordplay and humor to blur the boundaries between self and other, framing the microbiome as a challenge to the very notion of "what it means to be human." They capture the microbiome zeitgeist in their conclusion that "notions of the self have become diluted and pluralized and 'man's'

dominion over nature is questioned" (32). Across these instances is expressed a normative form of self-inquiry: a performative reckoning with identity that implicates audiences in the performance of self-examination as a matter not only of microbes, but also of civilization, society, and human history. In short: we are our microbes.[14]

The growing consciousness of microbial life led quickly to a widespread reshaping of microbial practices. In terms of the personal microbiota, the media frequently championed fermentation, probiotic therapy, and other means of cultivating a healthy microbiome. In the medical sphere, practitioners reevaluated approaches to antibiotics and the treatment of chronic disease. Meanwhile, the tools of metagenomic sequencing also sparked shifts in industrial practice, stemming from new attention to the flows, threats, and promises of microbes in industrial spaces from artisanal cheese shops to slaughterhouses and beyond.[15] At stake, as Heather Paxson has written, was a new regime of *post-Pasteurianism*, a transition away from "treat[ing] the natural world as dangerously unruly and in need of human control" and toward a view that "emphasizes the potential for cooperation among agencies of nature and culture, microbes and humans" (161). While such changes are not solely traced to microbiomics, humans' engagements with microbial life were certainly changing everywhere. At various scales and in various spaces, microbes had become newly collaborative as friends and helpers.

Yet for all its promise of new horizons and new engagements with the microscale, this growing American consciousness of the microbial world has been heavily influenced by a central tension between plenitude and loss. Across microbiome discourse, one's microbial contingent was

[14] Social sciences and humanities have eagerly embraced the idea that the new science of microbiomics irreversibly alters our sense of self, e.g., (Alice Beck) on microbes as companion species, (Kyla Schuller) and (Eva Hayward) on the refiguration of personhood and agency prompted by new infection models, and (Elizabeth Wilson) on the implications for feminist theory of embracing the biology of gut, brain, and bacteria.

[15] (Dunn) describes changing relationships to *E. coli* in corporate spaces, (Wentworth) in slaughterhouses, and (Paxson) in artisanal cheese production.

consistently depicted as a rather precarious entity, imperiled by the conditions of modern life. For as much as scientists and journalists celebrated the newly-visible abundance of the microbiota, the entire discursive field of the microbiome has always oriented itself around the theme of loss and insufficiency, advancing the claim that the human microbiome is damaged by the overzealous quest to eradicate disease. Like NPR's Silhouette Man, human bodies were said to suffer the consequences of life in an antiseptic world. And so even as microbiome research celebrated abundance, it continually suggested that the modern microbiota is a shadow of what it should be. To an extent, this contradiction arises from the biomedical imperative of microbiome research, with its exploration of microbiota differences relating to disease outcomes, a focus necessary for funding. It also relates to the field's sustained interest in the microbiota of indigenous peoples, which are frequently taken to be glimpses of an ancestrally whole microbiome untouched by the disrupted diets, antibiotics, and practices of the modern world.[16] Indigenous peoples are held up as exemplars of both the healthy microbiome and their means of stewarding it: across microbiome discourse runs a pronounced reverencing of ancestral practices, frequently used to argue for the necessity of returning to fermentation, microbiome-boosting diets, unmediated childbirth, and more.

In contrast, Western bodies are depicted as radically depopulated of their germs. Countless books and articles enumerate the aseptic habits of modern life: hand sanitizers, processed food, Cesarean delivery, and especially, the overuse of antibiotics. These are often described as forms of violence against the bodily landscape and are couched within the catastrophic register of climate change and other manmade disasters. For instance, Jeff Leach, a co-founder of American Gut's

[16] For instance, Clemente et al. (2015) evaluate differences between Western microbiota and those of a hunter-gatherer people in the Amazon, the Yanomami. This approach, which takes the reduced diversity of the Western microbiota to be indicative of "life-style practices that decrease microbial survival and transmission" (1) relative to the more whole ancestral microbiota, is widespread. See Geroux for a sustained critique of Native microbiota commodification in Clemente et al., and Hobart and Maroney for a broader discussion of how microbiome research continually localizes resources in indigenous bodies.

citizen science project in which individuals submit microbiome samples in exchange for their metagenomic data, has written that "the scorched earth outcome of many broad-spectrum antibiotics is analogous to spraying poison all over your backyard plants and grass" (Leach). The human microbiota thus resembles the damaged flora of the macroscale world, heading for manmade disaster as the impulse to treat disease runs out of control. Geographer Jamie Lorimer has written that the rhetoric of loss is central to the microbiome era, driven by a focus on "the significance of absences (rather than excessive presences) as the cause of … pathologies" (33). Those absences are manmade, reflecting a derangement of the ancestral microbiome; human progress culminates in the radical depletion of the body's ecological context.

This tension between ancient and modern, plentiful and deficient underlies the entirety of microbiome discourse and its mobilization. It is a tension felt at a broad scale. In both scientific writing and science journalism, modern bodies are said to suffer the consequences of their lost germs. The toll is often described in the form of epic catalogue: diabetes, obesity, asthma, autoimmune disease, allergies, autism, sickle cell anemia, heart disease, heartburn, vision problems, tooth problems, cancer, anxiety, and more—all newly prevalent with their rates skyrocketing. But these are not merely physiological maladies; they are expressed as forms of bodily nostalgia for lost microbes. The microbially-depleted body is often said to yearn for its past wholeness, experiencing a nostalgic pain at being separated from its ecological context. Biologist and science writer Rob Dunn: "whether lying in bed or sitting in front of your computer, when you ache, you ache with the history of your origin. You ache with the context you miss." Science journalist Moises Velasquez-Manoff imagines that loss at a global, historical scale. In his 2012 book *An Epidemic of Absence,* he suggests that humans are experiencing an "extinction spasm" that if left unchecked threatens to bring about a new era "characterized not by new life forms but by biological impoverishment. It might be

appropriately called the 'Eremozoic Era,' the Age of Loneliness" (144). The application of this sentiment to the internal world of the human body encapsulates the microbiome-era sentiment that we are living through a loss of microbial diversity at an epochal scale, in a catastrophic undoing of human-microbe ecology.[17]

Such proclamations of microbial precarity undergird the persistent advocacy for pro-microbial practices that pervaded American discourse in the wake of the HMP. Everywhere was evident a frantic obsession with reversing the damages of modernity. Fecal transplants, vaginal swabbing of Cesarean-delivered babies, deliberate rewilding with worms and germs: these and more are figured as acts of redemption for the transcendent destructions of antibiosis. "Probiotic approaches figure the present as already disastrous," writes Lorimer. "They seek to reverse, restore or otherwise address deleterious existing transitions" (36). And because these approaches occur within a context of moral (and mortal) peril, they readily lead to a sense of microbial obligation—the idea that one ought to eat, birth, wash, *exist* for the sake of one's microbes. Such claims are frequently hyperbolic, symptomatic of what UC Davis phylogenomicist Jonathan Eisen has termed *microbiomania:* "the overselling of the impact (beneficial or detrimental) of microbiomes without the evidence to support such impact" (J. Eisen, "Rediscovering Some Critical Terms of Use in Microbial Discussions").[18] My aim in this project is to interrogate the mania of such obligations, showing how—even if they mark a necessary re-apprehension of microbial life—they also they bind audiences and bodies into microbial obligation by pledging allegiance to a mythical ancestral past.

---

[17] Velasquez-Manoff is quoting E. O. Wilson's *Consilience*; through this reference he equates lost microbial diversity with global ecology.

[18] Eisen's concerns have been shared widely by other scientists. In 2012, Slashinski et al. described the "snake-oil" claims already pervading microbiome research as the ideal of health was quickly transformed into "public value" at the expense of scientific accuracy (2). Similarly, in a high-profile 2014 commentary, Hanage observed that excitement over the microbiome "has infected the public imagination" (247). More recently, Ma et al. have surveyed ethical problems resulting from microbiome commercialization and hype, including fecal transplants, microbial biobanking, and more.

This study situates the rhetoric of loss in microbiome discourse within the scientific and imaginative legacy of germfree animal research, also known as *gnotobiology*.[19] Gnotobiology, which originated simultaneously with germ theory, has been a primary avenue through which researchers have come to understand the intricacies of host-microbe ecologies. As such, it has had a significant impact on the scientific justification of microbiome research. I aim to show how gnotobiology, particularly its animals contained in carefully engineered isolators, has had a structuring influence on how fiction and nonfiction writers articulate the costs of germicide and the value of the microbiome. For as long as microbiology and popular culture have oriented themselves around an eradicative approach to microorganisms, they have also told stories of germophobia gone astray. In speculative tales of germfree bodies, enclosures, and planets they have used the figure of the germfree organism to warn of the consequences of misunderstanding the vitality of microbes for human life. Across decades, nationalities, and genres, germfreeness—both real and imagined, but always catastrophic—has served to critique and to deter the prevailing attitude of antibiosis. The rich history of germfree disaster scenarios has in turn had a structuring influence on the development of the microbiome, both conceptually and in its cultural dissemination, emphasizing once more that we simply cannot do without our microbes.

2. Methods and Context

Microbiology, of course, is a discipline that cannot be understood without attention to how it renders invisible life. Academic analyses of how microorganisms are made visible to human observers have generally focused on studies of visualization practices and illustration.[20] In this

[19] From the Greek roots *gnōtos* + *bios:* "known life."
[20] Microscopes and microscopists have featured prominently in literature from Margaret Cavendish's *The Blazing World* (1666) onward, and have been the primary focus of literary scholars' engagements with microbiology since Marjorie

project, I consider how microbes and microbiomes are made tangible through a different kind of rendering. "Any scientific statement about the world," Donna Haraway writes, "depends intimately upon language, upon metaphor… They structure scientific vision" (4). I examine this structuring influence in microbiome discourse, showing how its central claim for the inextricability of microbial and human bodies emerges alongside and from within innovations in language, metaphor, and narrative.

The meaning of "microbiome," and the term's association with the threat of microbial loss, has arisen within a complex interplay of fictional, scientific, and popular culture assessments of germfree life. Despite the vast scale of gnotobiology as a research enterprise and its perennial incursion into the American imagination, however, critical studies of gnotobiology's cultural significance are vanishingly scarce.[21] This project surveys the intellectual history of gnotobiology, particularly in its inception and implementation in the late nineteenth century. But as I show in Chapter 1, germfree animals came into being alongside the imagination of germfree humans. As scientists reckoned with the particular oddities and needs of animals devoid of germs, they always considered their subjects as model organisms—as models, that is, for human physiology and the bodily experience of disease. And although scientists used gnotobiotic specimens to make inferences about human life *with* microbes, they have always also served a figurative function as signifiers of a human future *without* microbes.

Hope Nicolson's seminal study, *The Microscope and English Imagination*. See (Peter J. F. Harris 2019) for a comprehensive recent survey of microscopes in literature, and (Chico) for a detailed analysis of their roles in 18th century narratives. Significant studies of microscopic visualization in the social sciences and humanities include (Hannah Landecker's) study of live-cell imaging technology and (Julie Sommerlund's) discussion of the interplay between science and aesthetics in the production of biofilm images. In a similar vein, (James Elkins) outlines the use of visual analogies in historical and contemporary microbial illustrations, while (Peter Heering's) reconstruction of an eighteenth-century solar microscope situates this popular form of microbiological showmanship within the visual culture of its time.

[21] Analysis of gnotobiology in fiction and popular culture is limited to two articles by Kirk, (2012a) and (2012b), and a chapter by (Weinstein). Adjacent literature includes (Julie Passanante Elman's) study of David Vetter, "the bubble boy."

Germfree humans, whether enclosed in an isolators or in worlds, have guided perceptions of human-microbial ecology. They appear across the boundaries of genre and discipline, in sustained fictions as well as in more glancing tropes and allusions. In detailing the imaginative legacy of gnotobiology, I turn frequently to science fictional tales of germfree apparatus and post-microbial apocalypse. These make use of science fiction's propensity for imagining the future in order to envision the final outcomes of the regime of antibiosis. Historically, they have therefore served as a testing ground in which to articulate the ethical and human risks of the desire (and the real effort) to get beyond the vicissitudes of life with microbes.

My use of fiction, however, is not confined to science fiction, nor to the confines of literary production, for as Laura Otis argues, "the relationship between literature and science is one of mutual feedback and suggestibility, each contributing to and drawing upon the 'cultural medium' out of which it grows" (3). Like Otis, I attend to "common metaphors and maneuvers" (3) shared across disciplinary borders, in this case through which the history of germfree research and speculation impacts on the microbiome present. Germfree speculation sometimes presents itself as overtly fictional, but not always: it also surfaces in smaller, but still imaginatively charged, ways within genres that have traditionally disavowed fictionality. I survey the theme of germfree disaster across fiction, professional scientific writing, and popular science. Across these genres are found moments of germfree speculation, sometimes overtly fictive and sometimes in the guise of nonfiction; they are bound together by a common set of speculative tropes, stock figures, and rhetorical patterns. In articulating the various devastations of isolated bubble inhabitants, or of civilizations that have transcended microbes altogether, scientists, writers, and journalists signal their debt to past conceptions of germfree life for a microbiome present in which absence is entirely unthinkable.

My study of these texts reflects a departure from the dominant scholarly mode of studying microbiological fictions, which historically have centered around disease narratives and the heroic bacteriologists and epidemiologists that populate them. In fiction, as in life: so entrenched are these narratives that they have become endemic, as Kari Nixon and Lorenzo Servitje suggest. They write that "epidemic discourse so thoroughly structures our world that it is endemic to our processes of social construction. That is, our current social constructions rely on paradigms that represent nearly everything as communicable" (3). This study seeks to look beyond the endemicity of contagion, searching out other narratives through which our culture has traditionally rendered microbial life. In this I join a small cadre of scholars who, in light of the advent of microbiomics, have begun excavating other narratives, exposing the more inclusive imaginings of humans and microbes that have always coexisted alongside the doom and gloom stories.[22] Like them, I emphasize that contemporary understandings of microbes are not entirely new. Microbiome discourse did not originate the invocation of bubble boys and germfree planets but rather answers to a long history of such visions, remaking but not inventing them.

Certainly, as journalists, scientists, and writers have attempted to make sense of the microbiome in the past decade, they have drawn on the fictions and tropes of generations past, turning to these depictions of germfree life as a shorthand for devastation and loss. Germfree speculation shares a common functionality of leading readers to appreciate the presence of microbes in their bodies and world through the imagination of their absence. Almost without fail, such

[22] (Kym Weed), for instance, assesses the longstanding trope of "friendly microbes" in nineteenth-century fiction and bacteriology, while (Garth Sabo) explores stories of microscale journeys into the "fecological body" in fictions of the same time period. Kari Nixon, in *Kept from All Contagion,* approaches the question of microbial necessity from a different angle, showing how nineteenth-century writers critiqued germ theory and the associated belief that isolation from germs and from community would be life-preserving by depicting pure spaces "as not simply antiseptic and without contamination, but … incapable of sustaining *thriving* life" (6, emphasis mine). From a more contemporary set of texts, (Laurel Bollinger) has called for "revisiting the infection metaphor in science fiction" in light of microbiome research.

fictions are catastrophic on some level, operating as warnings intended to question the eradicative approach to microbes. In the microbiome era, those warnings have reemerged as urban legends, as things already known. Familiar tales of bubble boys and germfree planets thus intensify their central claims in order to further arguments for what us at stake in the new science of microbiomics—namely, the possibility of germfree suffering, as invoked in the sufferings of bubble boys and germfree societies.

Microbiologists as a group are remarkably cognizant of the language they use to describe their subject matter, even if the figurative aspects of their writing often go unnoticed.[23] Microbiome scientists have been especially attuned to the power of language in advancing scientific knowledge, for instance by assessing in formal and informal ways how to use metaphorical paradigms to characterize their research.[24] In an early argument for what would become the microbiome concept, Lederberg situated human-microbial ecology within the grand 400-year history of microbiology in arguing that the next big leap would come from reexamining ourselves in relation to our microbes. But reexamining the metaphors had to come first: the classic metaphor of a war between human and microbial cells needed to "evolve." He wrote that "perhaps one of the most important changes we can make is to super[s]ede the 20th-century metaphor of war for describing the relationship between people and infectious agents" ("Infectious History" 293). Five years later, a group of scientists gathered to concretize a new approach to disease biology (*Ending the War Metaphor*). Nodding to

---

[23] Helmreich writes of social sciences approaches to the microbiome that overlook its meaning as produced by language: "The microbiome is a novel kind of object or figure in biology, to be sure, but its multiple meanings do not themselves follow from the fact that microbiomes are composed of a multiplicity of organisms… These are descriptions, metaphors. The microbiome, among all that it might also be, is a representation, a figure" (65). Indeed, the uncritical assertion that microbiomics has fundamentally reshaped our sense of self, without considering the influence of scientific rhetoric, is rampant. For Helmreich, and for this project, trusting too much in the revolutionary potential of the microbiome means overlooking its constitution through language.

[24] E.g., gastroenterologists (Nitin K. Ahuja and Amisha Ahuja) on the "symbolic lineage" of metaphors undergirding the microbiome; gastroenterologist (Vincent Baty et al.) on how scientists might harness microbiome metaphors to influence public understanding and healthcare policy; and geneticist (Eric T. Juengst's) bioethical analysis of the multiple metaphorical frameworks arising from the HMP.

Lederberg, who was among them, they sought new metaphorical horizons—not merely to popularize and make it catchy—but to drive forward the research enterprise itself, a critical step in stemming the tide of emerging diseases and antibiotic resistance. The microbiome as entity and as a research focus stood to rescue humans from this germy catastrophe.

But the scientific use of entrenched narratives and speculations often exceeds overt fictions and engineered metaphors. Throughout this project, I analyze scientific texts as rhetorical objects, showing how they deploy tropes of germfree life in order to persuade—chiefly, about the value of the microbiome, its research and funding, and its essential relationship to human and planetary life.[25] Quite often the use of germfree fiction and speculation is subtle, present in small moments and passing gestures that are not announced as fictional or rhetorical. Yet when considered across a wide number of texts, they cohere into a consistent representation of the dire stakes of germfree life.

For example, in the "Ending the War Metaphor" workshop summary referenced above, the researchers suggested that a major advance for the public would occur "if medical professionals encourage their patients to appreciate the benefits associated with the microbial flora and fauna that exist on and in us, and indeed *to recognize that without these microbes, life as we know it would not exist"* such that eventually "people may be able to declare a truce in the war on germs" (27-8, emphasis mine). This is a passing moment, unremarked and not presented as a fictional or speculative trope. Nevertheless, it deploys the counterfactual vision of life without. What is more overt in the story of NPR's Silhouette Man is evident more subtly here: that even a glimpse of the possibility of life without germs should cause us to reach for our microbes.

Such gestures are utterly pervasive throughout microbiome discourse, stemming as this project shows from a rich history of germfree animal research and speculative germfreeness.

---

[25] My focus on the persuasive aims of microbiome discourse builds on the approaches taken by rhetoric scholars assessing its language transformations, especially (Jason Kalin and David Gruber) and (Jennifer Saltmarsh).

Especially when embedded within medical and scientific writing, they are instances of what Sari Altschuler calls "imaginative experiments": "the ways in which doctors and writers used their imaginations to craft, test, and implement their theories of health" (8).[26] In these and countless other examples, writers subtly assert the power of the germfree imagination, namely, that the witnessing of catastrophic sterility interrupts the civilizational trajectory in which we find ourselves sick, depleted, dysbiotic. In other words, the speculation intrudes on material practices in our real world.

In the NPR video and everywhere else, catastrophic germfreeness is a rhetorical device—a narrative lens—rendering visible what is present but at risk in our modern world. Through witnessing the catastrophe of devastated landscapes and bodies, microbiome discourse argues for the necessity of seeing what we have heretofore overlooked. The germfree speculation device is thus both a hypothetical (a "what-if?") and a means of identifying what is real, present, now. Through imagined absence, audiences gain awareness of what is present and also the risk posed to body and world by the regime of antibiosis: a real sense of present and future crisis.

3. Overview

This project apprehends the imaginative and material legacy of germfree life in the microbiome era. While my primary archive is comprised of American professional and popular science writing since 2012, from the HMP onward, I also consider the historical roots of these phenomena. Each chapter shows how the microbiome era, in different ways, rewrites the story of gnotobiology and the consequences of germfree aspiration.

---

[26] As Susan Merrill Squier observes, metaphor and imagery are particularly productive features for analyzing the latent structures of thought animating biomedical discourse. "The very fact," she writes, that these "are thought to be sites extraneous to science suggests the investment science has in the marginality and obscurity enabled by those discursive modes. Thus we can look to imagery and metaphor for the expression of excess fantasy and desire, finding therein those sites of unresolved tension, cultural paradox, and stubborn ambiguity that are a crucial, if generally overlooked, aspect of biomedicine" (15).

I take the concept of *membrane rupture* to be a guiding principle throughout. Germfree life is precariously embodied, dependent on rigorously maintained barriers to separate sterile and germy spaces. Those membranes can break, leading to a rupture in which microorganisms might influx suddenly into sterile bodies—wide-open spaces susceptible to uncontrolled infection. The threat of the ruptured membrane is imagined and reimagined pervasively across microbiome discourse, particularly in arguments for the responsible restoration of damaged microbiota. But even when a germfree membrane is securely maintained, the lives within are depicted as ruptured from the ecological contexts to which they belong in a fracturing of the evolutionary associations between micro- and macroscale life. Such disturbances are not merely biological; germfree life is also widely suggested to sever an individual from the familial and social bonds that constitute their humanity.[27] Germfree membrane ruptures, whether artificial or natural, spontaneous or inevitable, real or imagined, sustain microbiome discourse's central theme that the separation of life into germy and germfree spaces is a violation of the ecological and social fabrics of human life.

My study of the threat of membrane rupture encompasses natural childbirth discourse, microbiome popular science, and the continual reappearance of membrane-bound gnotobiotic specimens both human and animal. Contemporary narratives of germfree life emphasize the biological risk of membrane rupture as well as the tangible suffering of individuals ruptured from societal wholeness. Both currents are used to neutralize the dream of germfree life and to redirect the reader to an appreciation of microbial necessity—but also to justify the moral obligations so often articulated in relation to the microbiome. The spectacle of germfreeness undergirds claims for

[27] Several distinct definitions of "rupture" are in play here. Biologically speaking, germfree bodies exhibit "a break, tear, or split in a surface or substance," in this case from their ecological companions. But they also resonate with definitions that suggest linkages to the social and political human world, reflecting both a "breach or violation of a treaty, contract, etc." and "a breaking off of friendly relations between individuals, groups, or nations; a rift, a separation" ("Rupture, n." definitions 1.a., 4.a., and 5).

how we ought to live, as microbes become our personal obligations in carrying the weight of human connection. I title the project *Ruptures* in recognition of this central dynamic.

Chapter 1 analyzes historical representations of individuals, groups, and planets rendered germfree, showing how the engineering of germfree laboratory animals in the late nineteenth century launched a mode of subtractive thinking in which the necessity of microorganisms is revealed through their imagined absence. I trace fiction's longstanding preoccupation with germfree spaces, in addition to scientists' use of elaborate global apocalyptic scenarios to describe the consequences of speculative microbial disappearance. The chapter concludes with a discussion of how both strains of germfree speculation have been deployed in microbiome rhetoric as a means of emphasizing the microbial-eradication paradigm as a threat to our very humanity.

Chapter 2 considers germfree life more narrowly at the scale of individual animals and humans confined within bubble enclosures. I follow the thread of the original "bubble boy" David Vetter, showing how his life was narrated in terms consistent with preceding depictions of germfree catastrophe, and how microbiome discourse has adopted the cultural censure of "life in a bubble" that has solidified since his death. I show how bubble kids, as well as germfree animals more generally, are recruited into microbiome discourse as figures for the human toll of antibiosis. In the hands of microbiome popular science writers, the suffering of human and animal lives ruptured from their ecological contexts represents the looming future of humanity should the progress of antibiosis continue unabated.

Chapter 3 turns to contemporary natural childbirth discourse, showing how the widespread celebration of a mother's role as microbiota donor to her child is recast as a problem of germfree membrane rupture. I analyze a corpus of scientific texts focusing on maternal microbiome transfer at birth, showing how these collectively rewrite historical narratives of germfree worlds in

emphasizing delivery mode—vaginal birth or C-section—as a consequential passage from germfree uterus to germy world. In doing so, they forge arguments for the planetary stakes of an individual mother's birth choices, weighting delivery with an obligation to the microbial future at the expense of the mother herself.

Chapter 4 presents an alternative to the pervasive themes of microbial absence and the frequent weight of obligation that mothers—and everyone—are often made to carry in the name of microbiome preservation. I outline the development of a novel mode of conceptualizing human-microbial relationships through metaphors of bacterial language and sociality. As microbiome research has moved away from its initial cataloguing phase and into the horizon of translational medicine, the microbiota have begun metaphorically talking with their human hosts. I show how research into the gut-brain-microbiome axis is harnessing these language and sociality metaphors to describe potential partnerships between germs and host, thereby characterizing their symbiotic relationship as one of mutual agency and collaboration. Such metaphors provide an alternative vision of human-microbial symbiosis, rejecting the microbiome-era theme of germfree suffering by casting bacteria as agential participants in a conscientious human-microbial alliance.

Works Cited

Arthur, Benjamin and Rob Stein. *The Invisible Universe of the Human Microbiome*. NPR, 2013, https://www.youtube.com/watch?v=5DTrENdWvvM.

Ahuja, Nitin K., and Amisha Ahuja. "Gastroenvironmental Distress: Metaphorical Antecedents of the Gut Microbiome." *Medical Humanities*, vol. 42, no. 2, June 2016, pp. 121–27.

Altschuler, Sari. The Medical Imagination: Literature and Health in the Early United States. University of Pennsylvania Press, 2018.

Arbanas, Caroline. "Census of Microbes in Healthy Humans Reported." *News Room | Washington University in St. Louis*, 13 June 2012, https://source.wustl.edu/2012/06/census-of-microbes-in-healthy-humans-reported.

Bäckhed, Frederik, et al. "Host-Bacterial Mutualism in the Human Intestine." *Science*, vol. 307, Mar. 2005, pp. 1915–20.

Baty, Vincent, et al. "Gut Health in the Era of the Human Gut Microbiota: From Metaphor to Biovalue." *Medicine, Health Care and Philosophy*, no. 17, Mar. 2014, pp. 579–97.

Beck, Alice. "Microbiomes as Companion Species: An Exploration of Dis- and Re-Entanglements with the Microbial Self." *Social & Cultural Geography*, vol. 22, no. 3, 2019, pp. 357–75.

Bollinger, Laurel. "Containing Multitudes: Revisiting the Infection Metaphor in Science Fiction." *Extrapolation*, vol. 50, no. 3, Jan. 2009, pp. 377–99.

Casadevall, Arturo, and Liise-anne Pirofski. "Host-Pathogen Interactions: Redefining the Basic Concepts of Virulence and Pathogenicity." *Infection and Immunity*, edited by V. A. Fischetti, vol. 67, no. 8, Aug. 1999, pp. 3703–13.

Chico, Tita. "Minute Particulars: Microscopy and Eighteenth-Century Narrative." *Mosaic*, vol. 39, no. 2, June 2006, pp. 143–61.

Clemente, Jose C., et al. "The Microbiome of Uncontacted Amerindians." *Science Advances*, vol. 1, no. 3, Apr. 2015, p. e1500183.

Cooper, Melinda. "Pre-Empting Emergence: The Biological Turn in the War on Terror." *Theory, Culture & Society*, vol. 23, no. 4, July 2006, pp. 113–35.

Diehl, Laura. "American Germ Culture: Richard Matheson, Octavia Butler, and the (Political) Science of Individuality." *Cultural Critique*, vol. 85, Fall 2013, pp. 84–121.

Dunn, Elizabeth. "Escherichia Coli, Corporate Discipline and the Failure of the Sewer State." *Space and Polity*, vol. 11, no. 1, Apr. 2007, pp. 35–53.

Dunn, Rob. The Wild Life of Our Bodies: Predators, Parasites, and Partners That Shape Who We Are Today. Harper Collins, 2011.

Eisen, Jonathan. "Badomics Words and the Power and Peril of the Ome-Meme." *GigaScience*, vol. 1, no. 1, Dec. 2012, p. 6.

---. "Rediscovering Some Critical Terms of Use in Microbial Discussions: #microbiomania and #microbophobia." *Jonathan Eisen's Lab Website*, 30 Oct. 2014, https://phylogenomics.me/2014/10/30/rediscovering-some-critical-terms-of-use-in-microbial-discussions-microbiomania-and-microbophobia/.

---. "What Does the Term Microbiome Mean? And Where Did It Come from? A Bit of a Surprise .." *MicroBEnet: The Microbiology of the Built Environment Network*, 8 Apr. 2015, https://microbe.net/2015/04/08/what-does-the-term-microbiome-mean-and-where-did-it-come-from-a-bit-of-a-surprise/.

Elman, Julie Passanante. Chronic Youth: Disability, Sexuality, and U.S. Media Cultures of Rehabilitation. New York University Press, 2014.

Ending the War Metaphor: The Changing Agenda for Unraveling the Host-Microbe Relationship - Workshop Summary. National Academies Press, 2006, p. 11669.

Falk, Per G., et al. "Creating and Maintaining the Gastrointestinal Ecosystem: What We Know and Need To Know from Gnotobiology." *Microbiology and Molecular Biology Reviews*, vol. 62, no. 4, Dec. 1998, pp. 1157–70.

Geroux, Robert. "The Uncolonized within the Uncolonized: Scientific Desire and a Speculative Reading of the Indigenous Biome." *Theory & Event*, vol. 23, no. 4, Oct. 2020, pp. 1037–52.

Hanage, William P. "Microbiology: Microbiome Science Needs a Healthy Dose of Scepticism." *Nature*, vol. 512, no. 7514, Aug. 2014, pp. 247–48.

Haraway, Donna Jeanne. Primate Visions: Gender, Race, and Nature in the World of Modern Science. Routledge, 1989.

Harris, Peter J. F. "Microscopy and Literature." *Endeavour*, vol. 43, no. 3, Sept. 2019, p. 100695.

Hayward, Eva. "Cat's Cradle: AIDS, Toxoplasmosis Gondii, and Impurrrfect Love." *Antennae*, no. 37, 2016.

Heering, Peter. "The Enlightened Microscope: Re-Enactment and Analysis of Projections with Eighteenth-Century Solar Microscopes." *The British Journal for the History of Science*, vol. 41, no. 3, Sept. 2008, pp. 345–67.

Helmreich, Stefan. "Homo Microbis: Species, Race, Sex, and the Human Microbiome." *Sounding the Limits of Life: Essays in the Anthropology of Biology and Beyond*, Princeton University Press, 2016, pp. 62–72.

Hobart, Hi'ilei Julia, and Stephanie Maroney. "On Racial Constitutions and Digestive Therapeutics." *Food, Culture & Society*, vol. 22, no. 5, Oct. 2019, pp. 576–94.

James Elkins. "On Visual Desperation and the Bodies of Protozoa." *Representations*, vol. 40, Fall 1992, pp. 33–56.

Juengst, Eric T. "Metagenomic Metaphors: New Images of the Human from 'Translational' Genomic Research." *New Visions of Nature*, edited by Martin A. M. Drenthen et al., Springer Netherlands, 2009, pp. 129–45.

Kalin, Jason, and David Gruber. "Gut Rhetorics: Toward Experiments in Living with Microbiota." *Rhetoric of Health & Medicine*, vol. 1, no. 3–4, Dec. 2018, pp. 269–95.

Kirk, Robert G. W. "'Life in a Germ-Free World': Isolating Life from the Laboratory Animal to the Bubble Boy." *Bulletin of the History of Medicine*, no. 86, 2012, pp. 237–75.

---. "'Standardization and Mechanization': Germ-Free Life and the Engineering of the Ideal Laboratory Animal." *Technology and Culture*, vol. 53, no. 1, Jan. 2012, pp. 61–93.

Landecker, Hannah. "The Life of Movement: From Microcinematography to Live-Cell Imaging." *Journal of Visual Culture*, vol. 11, no. 3, 2012, pp. 378–99.

Leach, Jeff. "Why We Need Germs." *The Saturday Evening Post*, 26 Feb. 2013, https://www.saturdayeveningpost.com/2013/02/good-bacteria/2/.

Lederberg, Joshua. "Infectious History." *Science*, vol. 288, no. 5464, Apr. 2000, pp. 287–93.

---. "'Ome Sweet 'Omics-- A Genealogical Treasury of Words." *The Scientist*, Apr. 2001, http://www.the-scientist.com/?articles.view/articleNo/13313/title/-Ome-Sweet--Omics---A-Genealogical-Treasury-of-Words/.

Lederberg, Joshua et al. "Ellison Medical Foundation One-Day Symposium." *Ellison Medical Foundation One-Day Symposium*, http://www.grg.org/EllisonCalTech.htm. Accessed 2 Feb. 2016.

Leeuwenhoek, Antony. *The Select Works of Antony van Leeuwenhoek*. Translated by Samuel Hoole, vol. 1, 1800.

Lorimer, Jamie. "Probiotic Environmentalities: Rewilding with Wolves and Worms." *Theory, Culture & Society*, vol. 34, no. 4, July 2017, pp. 27–48.

Ma, Yonghui, et al. "Help, Hope and Hype: Ethical Considerations of Human Microbiome Research and Applications." *Protein & Cell*, vol. 9, no. 5, May 2018, pp. 404–15.

"Me, Myself, Us." *The Economist*, Aug. 2012, https://www.economist.com/science-and-technology/2012/08/18/me-myself-us.

Metchnikoff, Élie. "Sur la flore du corps humain." *Manchester Memoirs*, vol. xlv, no. 5, May 1901, pp. 1–38.

"'More than One Way to Be Healthy': First Map of the Bacterial Makeup of Humans Relies on MBL Innovations, Insights." *The University of Chicago Marine Biological Laboratory*, 13 June 2012, https://www.mbl.edu/blog/bacterial-map/.

National Research Council Committee on Metagenomics. *The New Science of Metagenomics: Revealing the Secrets of Our Microbial Planet*. National Academies Press, 2007, http://www.nap.edu/catalog/11902/the-new-science-of-metagenomics-revealing-the-secrets-of-our.

Nerlich, Brigitte. "'The Post-Antibiotic Apocalypse' and the 'War on Superbugs': Catastrophe Discourse in Microbiology, Its Rhetorical Form and Political Function." *Public Understanding of Science*, vol. 18, no. 5, 2009, pp. 574–90.

Nerlich, Brigitte, and Iina Hellsten. "Beyond the Human Genome: Microbes, Metaphors and What It Means to Be Human in an Interconnected Post-Genomic World." *New Genetics and Society*, vol. 28, no. 1, 2009, pp. 19–36.

Nicolson, Marjorie Hope. *The Microscope and the English Imagination*. Smith College Studies in Modern Languages, 1935.

Nixon, Kari. Kept from All Contagion: Germ Theory, Disease, and the Dilemma of Human Contact in Late Nineteenth-Century Literature. State University of New York Press, 2020.

Nixon, Kari, and Lorenzo Servitje, editors. *Endemic: Essays in Contagion Theory*. Palgrave Macmillan, 2016.

Otis, Laura. Membranes: Metaphors of Invasion in Nineteenth-Century Literature, Science, and Politics. The Johns Hopkins University Press, 1999.

Paxson, Heather. *The Life of Cheese: Crafting Food and Value in America*. University of California Press, 2013.

Pollan, Michael. "Some of My Best Friends Are Bacteria." *New York Times Magazine*, May 2013, pp. 36–44.

Relman, David A., and Stanley Falkow. "The Meaning and Impact of the Human Genome Sequence for Microbiology." *TRENDS in Microbiology*, vol. 9, no. 5, May 2001, pp. 206–08.

Rhodes, Rosamond, et al., editors. *The Human Microbiome: Ethical, Legal and Social Concerns*. Oxford University Press, 2013.

Richardson, Sarah S., and Hallam Stevens, editors. *Postgenomics: Perspectives on Biology after the Genome*. Duke University Press, 2015.

Rosebury, Theodor. *Microbes Indigenous to Man*. McGraw-Hill, 1962.

"Rupture, n." *OED Online*, www.oed.com/view/Entry/168984.

Sabo, Garth. "'Onward and Inward!': Through the Fecological Body with Twain and Chappell." *Arizona Quarterly: A Journal of American Literature, Culture, and Theory*, vol. 75, no. 2, 2019, pp. 55–76.

Saltmarsh, Jennifer. "Human Boundary Seepage, Bacterial Rhetorics." *Rhetorical Animals: Boundaries of the Human in the Study of Persuasion*, edited by Kristian Bjørkdahl and Alex C. Parrish, Lexington Books, 2018, pp. 61–80.

Savage, Dwayne C. "Microbial Ecology of the Gastrointestinal Tract." *Annual Reviews in Microbiology*, vol. 31, 1977, pp. 107–33.

Schell, Heather. "The Sexist Gene: Science Fiction and the Germ Theory of History." *American Literary History*, vol. 14, no. 4, Dec. 2002, pp. 805–27.

Schuller, Kyla. "The Microbial Self: Sensation and Sympoiesis." *Resilience: A Journal of the Environmental Humanities*, vol. 5, no. 3, 2018, p. 51.

Slashinski, Melody J., et al. "'Snake-Oil,' 'Quack Medicine,' and 'Industrially Cultured Organisms:' Biovalue and the Commercialization of Human Microbiome Research." *BMC Medical Ethics*, vol. 13, no. 1, Dec. 2012, p. 28.

Sommerlund, Julie. "Beauty and Bacteria: Visualizations in Molecular Microbial Ecology." *Configurations*, vol. 12, no. 3, 2004, pp. 375–400.

Squier, Susan Merrill. Liminal Lives: Imagining the Human at the Frontiers of Biomedicine. Duke University Press, 2004.

The Invisible Universe of the Human Microbiome. NPR, 2013, https://www.youtube.com/watch?v=5DTrENdWvvM.

Thomas, Lindsay Carroll. Training for Catastrophe: Fictions of National Security after 9/11. University of Minnesota Press, 2021.

Tomes, Nancy. "Epidemic Entertainments: Disease and Popular Culture in Early-Twentieth-Century America." *American Literary History*, vol. 14, no. 4, Dec. 2002, pp. 625–52.

---. The Gospel of Germs: Men, Women, and the Microbe in American Life. Harvard University Press, 1998.

Turnbaugh, Peter J., et al. "The Human Microbiome Project." *Nature*, vol. 449, Oct. 2007, pp. 804–10.

Velasquez-Manoff, Moises. An Epidemic of Absence: A New Way of Understanding Allergies and Autoimmune Diseases. Scribner, 2012.

Wald, Priscilla. Contagious: Cultures, Carriers, and the Outbreak Narrative. Duke University Press, 2008.

Weed, Kym. "Microbial Perspectives: Mark Twain's Imaginative Experiment in Ethics." *Literature and Medicine*, vol. 37, no. 1, 2019, pp. 219–40.

Weinstein, Matthew M. "Gnotobiology: Utopias of Science and Adolescence." *Bodies Out of Control: Rethinking Science Texts*, Peter Lang Publishing, Inc., 2010, pp. 17–27.

Wentworth, Kara. "Sensing Sentience and Managing Microbes: Lifedeath in the Slaughterhouse." *Mosaic: A Journal for the Interdisciplinary Study of Literature*, vol. 48, no. 3, 2015, pp. 141–57.

Wilson, Elizabeth A. *Gut Feminism*. Duke University Press, 2015.

Worboys, Michael. Spreading Germs: Disease Theories and Medical Practice in Britain, 1865-1900. Cambridge University Press, 2000.

"La vie impossible"

For more than a century, stories of illness have structured our understanding of microorganisms. Since the advent of germ theory, lay audiences, physicians, writers, and researchers have identified the presence of microbes through the experience of individual bodies wracked by infection; through communities, distorted by epidemic; through the experience of a world seeming to shrink as epidemics race across the globe. In this invasion paradigm, the human body falls ill upon the influx of pathogenic organisms. Disease results from incoming hordes that destroy the status quo, undoing bodies and societies; only their expulsion can restore health. In other words, ordinary life is entirely contingent upon the absence of invading microbes.

From its inception, microbiome research has demanded a disruption of this paradigm, calling into question the nearly exclusive emphasis on disease at the expense of other ways of understanding bodies and selves. Germfree bodies, both real and imagined, have been central to the effort to tell new stories of health and illness, and of humanity's relation to microbes on a germy planet.

In June 2012, as the Human Microbiome Project was poised to debut its first results, microbiome researcher and gnotobiologist Jeffrey I. Gordon wrote in the journal *Science* of the imperative to "honor thy gut symbionts." Gordon argued that it was important not only to look toward the future of microbiomics but also to look back so as to recover older ways of understanding the human body in relation to its microbes. Gordon's backward gaze falls upon the classic narratives with which he, and generations of microbiologists, had been raised:

> For some, learning about our gut microbiomes brings back childhood memories of reading Paul de Kruif's *The Microbe Hunters*, the historical narrative portraying the early heroes of microbiology. In the pages of that book, we saw our relationship with microbes portrayed in

> warlike, rather than in mutually beneficial, terms… Reading that book was to experience the thrill of the hunt for things unknown, the challenge of crafting a framework for not only identifying new microbes but for establishing what they do, and the triumphs of overcoming and ultimately preventing the diseases they cause. (1251)

For Gordon, as for other HMP advocates, it was time to leave behind a warlike approach to the microscopic world that was out of step with the new knowledge that "we are a splendid amalgamation of microbial and human cellular and genetic parts—more microbial than human in many ways" (1251). His article calls for a reassessment of the past that captures the enthusiasm and heroism of de Kruif's narration—"the current quest to understand the factors that forge the assembly, determine the stability, and effect the adaptations of our gut microbiomes is also thrilling" (1251)—while also reconnecting to older scientific approaches. Research into gut microbial communities, he notes, is a century old and had arisen from germfree animal studies. Gordon suggests that it is time to hunt for symbionts, not for pathogens, thereby restoring the tradition of understanding bodies as symbiotic communities. He sees this quest as no less heroic than those narrated by de Kruif, especially for a public already "captivated" by microbiome research and exhibiting a "fascination" with "new perceptions of ourselves" (1252).

Like Gordon, in this chapter I look back to the past in assessing gnotobiology's import for the microbiome present, though I track the narrative rather than the research legacy of germfree animal studies. Specifically, I trace how germfree worlds emerged in literature and science in response to—and in reaction against—more dominant narratives of microbial invasion and eradication. In this speculative genealogy, scientists and fiction writers imagine the consequences of bodies and worlds not *invaded* by microbes but instead, *devoid* of them. Though they adopt many of the tropes of invasion narratives, they detail the reverse: it is the absence of one's accustomed

symbionts that proves catastrophic. This mode challenges the premises of germ theory, furnishing an imaginative space within which to test the limits and consequences of germophobia.

Stories of germfree disaster, despite their grim speculations, are ultimately a hopeful alternative to conventional illness narratives. This is because they are more fully hypothetical, presented as the exploration of germophobic fantasy within an imaginative space that is not real. As such, they seek to influence engagements with microbes in the real world by teaching audiences to appreciate, and not to fear them. The rich but largely unrecognized tradition of germfree fiction emphasizes the contingency of Earthly life upon the presence of microorganisms. This is a different kind of germ theory: a germ theory of health and connectedness.

The trope of the germfree world has subsisted in an unbroken chain from the beginning of gnotobiology, both in fiction and in scientific writing. In tracing the ebbs and flows of speculatively germfree worlds, I show how microbiome research has inherited these precedents, continually rewriting them into parables for the wisdom of appreciating the microbes that constitute our bodies and planet—and which are plagued by the looming threat of real aseptic disaster. Microbiome discourse, as I show in the chapter's conclusion, acknowledges the recurring dream of getting beyond microbes even as it reprises the outcomes of germfree speculation. In doing so, it exposes germfree fantasy as an unmitigated disaster, a compelling insight for a contemporary audience increasingly recognizing the necessity of tending to the microbiome in the face of forces systematically threatening it.

1. The Isolation of Life

Germfree speculation is rooted in the work of Louis Pasteur. As a key practitioner of germ theory, he fully recognized the sequelae of infection. But as an experimentalist, he was also

accustomed to constructing germfree spaces. For instance, in his efforts to disprove the doctrine of spontaneous generation, he had sealed swan-neck flasks containing sterile nutrient broths and shown these to remain lifeless even decades later. His work was also guided by the more speculative imagination of germfreeness and its consequences. These fall into two general categories. In the first and historically earlier lineage of germfree speculation, Pasteur envisioned an Earth devoid of microbes; in the second, a vertebrate life artificially separated from its accustomed microflora. In each case, he imagined, the loss of microorganisms would result in catastrophe. Both lineages have persisted in the microbiological imagination ever since, growing increasingly elaborate and providing the microbiome era with a rich imaginative legacy of thought experiments, aphorisms, and narratives of catastrophic germfreeness with which to articulate its central claim about the essential role of microbes in our bodies and our world.

Near the end of his career, Pasteur proposed the creation of a germfree animal as a means of assessing the contribution of microorganisms to vertebrate biology. The germfree animal hypothesis was formalized in 1885 as a response to his group's work on plant microbiology. Writing in *Comptes rendus*, the journal of the French Academy of Science, Pasteur presented the findings of his student Emile Duclaux's study of plant germination in the absence of soil microbes.[28] Duclaux had sown beans and peas in sterile soils supplemented variously with milk, rock sugar, and starch paste—all food sources with known decomposition products. The plants grew into wispy stalks, weighing less than the seeds they had germinated from, and continued to decline in weight as time went by. Meanwhile, chemical assays revealed that the added nutrients remained entirely unprocessed. Duclaux wrote that his plants behaved, "despite the apparent fertility of the soil, as in the classical

[28] This work arose from a longer scientific interest in growing plants in self-contained artificial systems, including the chemist Jean-Baptiste Boussingault's experiments with distilled water in the early 19th century and Joseph Priestley's studies of photosynthesis in oxygen-deprived bell jars in the late 18th century.

experiments … on germination in distilled water" (68). In other words, the variety of sugars, starches, and milk proteins with which they were planted were useless without microbial processing, no more effective than distilled water. His plants were starving in the midst of abundant food.

Alongside Duclaux's paper, Pasteur appended a short proposal for an experiment he viewed as an extension of the plant study into vertebrates. Reasoning from analogy, he supposes that sterile animals would exhibit a similar inability to absorb food, manifest as dysfunctional digestion. He proposed to test this hypothesis using chicken eggs, with their protective shell presumably protecting a sterile embryo within. He wrote that the egg would be "deprived externally of any living dust," transferred into a sterile space with a germ-free air flow, and fed a diet that was abundant but sterile (68). Without gut microbes, he reasoned, the animal could not survive any better than Duclaux's beans and peas. He writes, "without wanting to affirm anything, I do not hide that I would undertake this study, if I had the time, with the preconceived idea that life, in these conditions, would become impossible *[la vie, dans ces conditions, deviendrait impossible]*."

Nothing like this had ever been done before. Though he is hailed as the father of gnotobiology, Pasteur never undertook the experiment himself, perhaps recognizing that the isolation, enclosure, and maintenance of germfree life would require immense labor and technical skill, especially in the years before antibiotics and easy monitoring for contamination. Others would eventually take on his proposal, developing gnotobiology into a robust research field as they engineered aseptic life, refined the technology enclosing it, and accommodated the unique needs of these organisms. The impact of Pasteur's hypothesis on the public imagination was also immediate and lasting. As sterile animals appeared in their self-enclosed isolators, so too did germfree people appear in the capsules, cylinders, clean houses, and cities of the future. The bizarre thought of a sterile organism dying without its microbes—trapped in "la vie…impossible"—would resound

across professional and popular scientific discourse for decades to come in recurring stories of isolated and suffering germfree humans.

The 1885 proposal sparked immediate controversy. Among scientists, there was debate as to the value of microorganisms to vertebrate life: were they friends or foes? would eliminating them lead to suffering, as Pasteur envisioned, or to liberation? To some, the elimination of microorganisms could bring only benefits. One of Pasteur's earliest and most influential critics, Polish chemist Marceli Nencki, felt that the germfree condition would improve the quality of life by removing toxic microbial byproducts. Whereas Pasteur believed bacteria to be essential for digestion, Nencki argued that animals secrete gastric juices that should suffice to break down food into digestible form. Microbes therefore held no benefit to the host: "the organism does not need them; they are to him, on the contrary, dangerous and annoying as soon as they occur in large quantities in the intestine" (387). Nencki's paper pivoted quickly from animals to potential implications for humans, anticipating a bright aseptic future of happy digestion: "I cherish the hope that one will succeed in obtaining the decomposition of nutrients in the digestive tube solely by our digestive juices and to free us from the annoying gases and smelly products" (387-8). In looking ahead to human implications, Nencki was among the first to imagine, however briefly, the quality of human life in a germfree space, for good (as he thinks) or for bad.

Nencki's stance was, of course, consistent with the general cultural attitude toward microorganisms in the late 19th century. The prospect of an organism dying without germs seemed contradictory for readers preoccupied with germ theory and with stories of disease apocalypse and other microbial horrors. The American journal *Science*, for instance, suggested that Pasteur's hypothesis would be a hard sell for a public resistant to the idea of "life-microbes":

> Owing to the fact that some microscopic organisms have been shown to play an important part in many forms of disease, we are somewhat in the habit of looking upon such organisms in general as our enemies, forgetting many useful purposes which they serve… While there are microbes which cause disease, there are others constantly at work keeping the conditions favorable to life. ("The Relations of Microbes to Life", p. 268)

Pasteur's hypothesis stood to challenge that view of microbes as enemies, to reveal them as friendly and even essential by demonstrating the costs of their removal.

Efforts to realize Pasteur's experiment began immediately. In Germany, George Nuttall and Hans Thierfelder began a sequence of painstaking experiments, constructing and refining a germfree chamber over a period of three years. It was immense and complex, requiring steam sterilization, temperature control, total elimination of moisture, and a perfectly airtight seal. The chamber held within it a lone newborn guinea pig, which Nuttall and Thierfelder had delivered via sterile Cesarean section and transferred immediately into the apparatus.[29] From here, the pup was fed and handled only with rubber gloves affixed to the exterior of the chamber (Figure 5).

[29] Nuttall and Thierfelder had found that using newborn chicks in the chamber, as Pasteur had proposed, led to constant contamination. However, their use of guinea pig pups was guided by his insight that developing embryos were germfree: they excised the mother's pregnant uterus and subjected it, whole, to chemical sterilization before opening it and transferring the pup to the chamber.

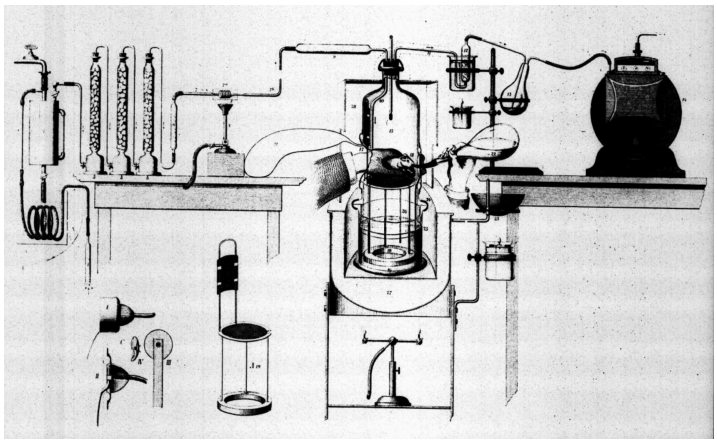

Figure 5. Nuttall and Thierfelder's landmark germfree apparatus. At the center of the diagram, two hands enclosed in externally-mounted gloves handle a germfree guinea pig.

In the paper announcing their successful isolation and maintenance of a germfree guinea pig, Nuttall and Thierfelder cited Nencki and noted that they too had begun their work skeptical of Pasteur's hypothesis. Their results seemed to bear this out, given the animal's survival and weight gain. The experiment concluded on day eight because the operators were exhausted by the constant maintenance, but the animal appeared to be still healthy. They concluded: "the question on which the experiments were undertaken, therefore, has been decided in the sense we have been expecting. The presence of bacteria in the intestinal canal is not necessary for the life of the guinea pigs, and therefore also of the other animals and of man" (119-120). Nuttall's and Thierfelder's experiment was widely hailed for its originality and technological achievement. Other groups would subsequently isolate germ-free chickens, mice, and other organisms using similar protocols.

And so life without germs was technically achievable. *But was it desirable?*, bacteriologists asked. *What consequences might such a life bring?* Writing in the same year as Nuttall and Thierfelder's landmark paper, J. Kijanizin at the University of Kiev had written a lengthy argument in defense of "the vital activity of microorganisms" in decomposition, fermentation, soil enrichment, and the sustenance of human and animal life. Germfree life to him seemed to contradict the significance of these various processes: "by creating a fully or partially microbe-free environment, we place the

animal in abnormal biological conditions" (343). In the same paper, Kijanizin reported research supporting his opinion. Placing rabbits and dogs in a microbe-depleted space with sterile inflowing air, he observed weight loss as well as a pronounced deficiency in nitrogen absorption from food relative to control organisms. Moreover, in most instances the animals kept in sterilized air died during the course of the experiment or shortly afterward; in other instances, they became "excessively exhausted, weak, but remained alive" (385).

Other experiments seemed to confirm physiological deficiencies in germfree organisms. German bacteriologist Max Schottelius returned to Pasteur's idea of creating germfree chickens, introducing a number of refinements on his predecessors' methods that allowed him to successfully isolate a germfree chick. The chick lived but at a cost: it failed to gain weight and sometimes lost weight. Schottelius wrote that by the 17th day of the experiment, "the chicken was so weak that it—although continually consuming food and water—could hardly stand and would certainly be dead the next day" (241). Like Kijanizin's dogs and rabbits and Duclaux's beans and peas, Schottelius saw his chickens as impoverished, wracked by a radical insufficiency; they were stunted and weak, technically alive but rapidly expiring. For Schottelius, the struggles of the germfree condition indicated an evolutionarily-conserved relationship in which bacteria are actively protected by their host organisms in exchange for inducing "the vital energy of the body cells" (212). He writes that from an evolutionary perspective, "it would be impossible to understand why the stronger, better creature should contain exclusively pests within its interior" (212).

Schottelius' results were mirrored in a steadily increasing body of work from other laboratories: Bogdanow (1908) found that sterile flies exhibited developmental problems, while Olga Metchnikoff and Ernst Moro, working separately, found similar results in germ-free tadpoles. Metchnikoff, reporting that her tadpoles were stunted and small, concluded that "it can therefore be

affirmed that microbes are necessary for the life and development of tadpoles" even though it remained "to elucidate the entire mechanism of the microbial influence" (634). By 1912, Michel Cohendy—part of the Élie Metchnikoff group in France—declared that the necessity of microbes to higher organisms had become an "unbreakable principle of adaptation between animals and their bacteria, which principle seemed to impose itself on us as an established biological law" (137).

Cohendy, however, took issue with this consensus. The Metchnikoff group had begun questioning this "unbreakable principle," conducting a comparative survey of host-associated bacteria that revealed numerous instances of animals, like scorpions and dogfish, existing essentially germfree in nature. Moreover, their improvements on Schottelius' techniques would in fact allow sterile chicks to survive long-term with minimal problems: they grew and gained weight, developed normally, and could be reintroduced to bacteria without triggering immune problems. The researchers found that the digestive inefficiencies of germfree animals could be mitigated with increased feeding. Cohendy's paper predicts similar successes with additional vertebrate species in the near future and concludes that, with the right adaptations, "*Life without microbes is possible for a vertebrate—the chicken—normally provided with a rich microbial flora. This aseptic life itself leads to no decline of the body"* (135, emphasis in original). With sufficient adaptations, it seemed, germfree life could be sustained indefinitely.

Work by the Metchnikoff group and others gradually shifted the approach toward germfree life so that the question became not whether such a life was possible, but how it could be nurtured and sustained. By the mid-19th century, gnotobiology had grown increasingly flexible and powerful. Germfree organisms, most commonly mice (but also including poultry, nematodes, plants, and more), are now housed in research centers worldwide; they have contributed to research in physiology broadly, and especially to microbiome studies. Yet beyond their role as experimental

subjects and model organisms, germfree animals have from the start referred observers not only to insights about analogous processes in human bodies—each of the authors referenced above in some way extends their findings to prospective humans—but also to consider their relationships with germs in bodies yet to come. As germfree animals were imagined, and then literalized, accommodated and nurtured, so too was the persistent thought of the human life beyond germs. Fictional, popular science, and scientific texts were increasingly populated by germfree people, confined in metal and glass in isolators of the future.

As the 20th century dawned, germfree humans became a regular feature in the public imagination as newspapers and magazines eagerly transformed the research into speculations on the eventual transcendence of bodily limitations. Historian Robert G. W. Kirk has observed that these experiments were "extensively reported in the international press and interpreted to mean that germ-free life was not only possible but beneficial. When Cohendy reported that his germ-free animals grew quicker and larger than conventional animals, the *New York Times* quickly concluded that future 'children may acquire stronger constitutions by similar treatment'" (242).

Élie Metchnikoff himself was also prone to such speculations in his public communications. In a talk delivered at the Manchester Literary and Philosophical Society, he argued that even if bacteria have some positive roles in the human body, those benefits are outweighed by the constant risk of invasion by microflora that "at every moment can become infectious" (19). Claiming that bacteria are in fact directly responsible for the "injustice" of "the short duration of our life, which is extinguished before reaching its goal" (37), Metchnikoff envisioned (to what extent seriously, it is unclear) a futuristic program of systematically removing the microflora, effectively approximating the germfree state for humans. He suggested aggressive research into antiseptic methods, including

therapeutic treatments with antimicrobials harvested from animals. More memorably, he also proposed surgically excising organs prone to harboring infectious bacteria. He argued, for instance, that the stomach is a dispensable organ—so why not remove it, along with its microbes? Pointing to several examples of total stomach resection patients, he concluded that these "provide an important argument for the inutility of this body" (28).[30] He similarly described the small intestine as a repository for potentially dangerous organisms and therefore a candidate for surgical removal. He stated that "the small intestine is disproportionately developed. Instead of having a length of 5½ to 6½ meters, the man could be content with a third of that. Roux, the well-known Swiss surgeon, said during the discussion of intestinal surgery … that man can live very well with a meter and a half jejunum" (28). The satirical bent of his comments belie a serious point: that whatever benefits the microflora might confer, they are above all a hazard and a liability. A germfree, or approximately germfree, future can bring only benefits, correcting the "injustice" of early death by microbes.

Kirk has described similar enthusiasm for gnotobiology's applications in the public eye more broadly. He writes that coverage of germfree research led quickly to visions of germfree babies and dramatically lengthened lifespans, especially in science fiction: "By the 1920s, long before antibiotics, the ideal of germ-free living was well established as a characteristic of the imagined future" (242). Indeed, science fictional futures of the era were often germfree—especially in pulp fiction. Authors frequently presented life beyond germs as an achievement and an asset. For instance, germfree capsules were imagined as vehicles to the future. In George Parsons Lathrop's story "In the Deep of Time," a young test subject, Gerald Bemis, agrees to be "vivificated," that is, preserved for passage into the future. Bemis is "sealed up for futurity" in a sterilized linen garment, injected with *Mortimicrobium* to destroy all organisms not essential to life, and sealed into a glass cylinder filled with

[30] *The Pittsburgh Press* reported this lecture under the headline "Man's Stomach: Scientist Asserts that it is an Absolutely Unnecessary Organ."

antiseptic air (680). So enclosed, he waits for centuries to pass, to be transported into another time as a "child of the future" and a "candidate for futurity" (684). Similarly, M. P. Shiel's 1936 story "The Future Day" envisions a human race that has taken permanently to the air, traveling in aseptic ships so as to avoid contact with microbes on the earth's surface.

In physiological terms, germfreeness in fiction is often associated with extreme longevity. In the short story "Into the Green Prism" by A. Hyatt Verrill, the traveler Don Alfeo discovers a microcosmic village in which the tiny residents by virtue of having no germs, live upward of 200 years in a prolonged and healthful childlike state—"as near to Utopia as can be found on this earth" (1069). The same is true for Wallace West's "The Incubator Man," inhabiting his second century of life, and the futuristic New Yorkers of Hugo Gernsback's *Ralph 124C 41+*, whose devoted use of a "bacillatorium" device to kill their bacteria extends their lifespan to 120-140 years. And in the domestic space, both Gernsback and Charlotte Haldane (in *A Man's* World) depict aseptic cows, which produce excellent milk (Haldane) even if it is rather green (Gernsback).

Yet fictional imaginings of germfree people are rarely so celebratory as Kirk and these examples would suggest. Stories forecasting health and longevity are outnumbered by those that describe sterile living as a misguided or dangerous enterprise. Rather than being life-giving, the aseptic state most commonly produces isolated, precariously embodied organisms suffering within the sociopolitical regimes that produced them. Fiction has historically functioned as the dominant venue for critiques of germfree fantasy, allowing readers to envision the threats, costs, and deprivations of isolator life—the human toll of disregarding life at the microscale. Often positioned explicitly as a response to prevailing germophobic attitudes, these stories serve as an argument for living with germs and thus form essential precedents for microbiome-era narratives of germfree life.

2. Germfree States as Social Pathology

The deployment of speculative germfreeness to critique dominant germophobias dates to the beginning of both gnotobiology and science fiction. In tales of aseptic societies, writers have historically critiqued the dream of axenic life as ill-advised and as producing intellectual, social, or psychological deficiencies for those contained within.

H. G. Wells, in *The War of the Worlds,* first took the technologies of germfree life into fiction, recruiting them into a damning attack on the impulse to exterminate microbial life. The novel was written at a time of heightened public germaphobia as the association of microbes with disease took hold. In an 1899 issue of the American magazine *The Living Age,* one Henry S. Gabbett, M.D., captured the mood of the day in writing that "the maleficent germ is known to all men. Its atrocities are telegraphed to the newspapers, discussed in clubs, and shuddered at in the family circle." To many, he notes, "the public regards a 'bacillus' as a necessarily evil thing—nay as a veritable incarnation of the spirit of evil" (307). Gabbett identifies Wells' novel as an answer to this germicidal spirit. "But is their extermination desirable?" he asks before launching into a plot summary.

The War of the Worlds is not usually read as gnotobiotic fiction, but in fact germfreeness is a central conceit of the novel. Composed just two years after Nuttall and Thierfelder's landmark paper, it reflects its author's attunement to issues raised in the gnotobiology debates discussed above. Wells casts the Martians as masters of an aseptic world—a germfree chamber—of their own making, engineers of a technologically advanced civilization featuring interplanetary travel, death rays, and glittering, intricate tripods. In an echo of the extensive apparatus described in the gnotobiology literature, germfreeness is equated with intrusive, overwhelming technology.

Within their home planet, the Martians are radiantly healthy in a vision mirroring the predictions of Nencki, Metchnikoff, and Cohendy. Wells writes that "microorganisms, which cause

so much disease and pain on earth, have either never appeared upon Mars or Martian sanitary science eliminated them ages ago. A hundred diseases, all the fevers and contagions of human life, consumption, cancers, tumours and such morbidities, never enter the scheme of their life" (102). The Martians appear to be better off without germs; within their sterile borders, at least, they exhibit no deficits.

Yet there is something wrong with this condition, even if it does not manifest in physiological flaws. Wells presents the Martian pursuit of germfree life as symptomatic of an intellectual pathology, namely, the dangerous obsession with biological mastery of the body. His Martians are physiological caricatures of human rationality, featuring oversized heads atop shrunken bodies. These hypertrophied brains have also shaped their bodies so as to minimize biological unpredictability. In the narrator's concluding report on Martian physiology, he observes that the creatures have devised a means of bypassing the normal digestive process—here an echo of Pasteur's and other researchers' interests in the relationship between microbes and digestion—by converting to a diet comprised exclusively of animal blood:

> Strange as it may seem to a human being, all the complex apparatus of digestion, which makes up the bulk of our bodies, did not exist in the Martians. They were heads–merely heads. Entrails they had none. They did not eat, much less digest. Instead, they took the fresh, living blood of other creatures, and injected it into their own veins… blood obtained from a still living animal, in most cases from a human being, was run directly by means of a little pipette into the recipient canal.

Wells' decision to cast the Martians as feeding parasitically on human blood may well reflect contemporary scientific discourses surrounding germfree states in nature. Metchnikoff at this time was busy surveying microbial loads across animal species; in his Manchester remarks of 1901, he

observes that scorpions are essentially "parasite free," a condition that he notes results in part from their living on the blood of small animals. Blood, as he noted, "is a food that is digested very easily and which in most cases does not contain microbes" (13). In the novel, the Martians' scorpionlike feeding on blood is given as the result of systematic efforts to gain control over the germy process of digestion—much like Metchnikoff's vision of future stomachless humans. Wells writes that in bypassing digestion, the Martians are "lifted above all [the] organic fluctuations of mood and emotions" of germy digestion that in humans "sap our strength and color our mind" (100).

The War of the Worlds thus presents the germfree state of Mars and the physiological oddities of its inhabitants as arising from an obsession with rational control. Their engagement with human life on Earth embodies the same principle. Wells first introduces the Martians as turning a bacteriological eye toward Earthly humans from their own sterile world, watching us "perhaps almost as narrowly as a man with a microscope might scrutinise the transient creatures that swarm and multiply in a drop of water." In the narrowness of their gaze, humans are rendered eliminable in much the same way as the extinct germs of Mars. The aliens approach the planet antagonistically, driven to kill with never a gesture toward diplomacy; their ruthless destruction of life reduces humans to vermin, victims of germophobia.

Their exterminative agenda is also their downfall as, carried away with the destruction of life, they overlook the humble bacteria of planet Earth. Stumbling across the wreckage of a dozen silenced tripods, the narrator observes

> the Martians–dead!–slain by the putrefactive and disease bacteria against which their systems were unprepared … slain, after all man's devices had failed, by the humblest things that God, in his wisdom, has put upon this earth…. There are no bacteria in Mars, and directly these invaders arrived, directly they drank and fed, our microscopic allies began to work their

> overthrow. Already when I watched them they were irrevocably doomed, dying and rotting even as they went to and fro. It was inevitable. (135)

The tripods that have protected the Martians from human insults are thus revealed to be flawed in design, fatally open to the contaminated air of Earth. The novel suggests this flaw to be not a technological failure—the tripods were never meant to be self-enclosed systems—but rather as an oversight, a forgetting of their vulnerability and their own germy past.

It is a lesson that Wells surely intended as a warning. By incorporating gnotobiological theories and technologies into his depiction of Martian society, he implicitly represents Victorian bacteriology as both life-preserving and risky. *The War of the Worlds* diagnoses a disordered society unable to restrain its germicide to the safe confines of its world. Jack Williamson has written that in "sanitizing Mars, wiping out the native bacteria, they display their hubris, the fatal flaw, the arrogant pride that goes before the fall"(198). This hubris is both Martian and Earthly. Wells takes pains to establish the Martians as evolutionary descendants of humanity, despite their foreignness: they "descended from beings not unlike ourselves, by a gradual development of brains and hands … at the expense of the rest of the body. Without the body, the brain would of course, become a mere selfish intelligence" (102). These aliens are a cautionary tale of what might happen should humans, too, attempt to assert control over the material, microbial world. Wells writes that "we men, with our bicycles and road-skates, our Lilienthal soaring-machines, our guns and sticks and so forth, are just in the beginning of the evolution that the Martians have worked out" (103). Fiction thus intervenes in the trajectory of progress lest humans materialize a germfree fantasy for themselves; the sterile planet—or the sterile isolator—is troubling in its artifice, as a manifestation of

overweening ambition.[31] The stakes are nothing less than our very humanity: as the Martians show, the further we retreat from our microorganisms, the less human we become.

Elsewhere in fiction, authors have followed Wells' lead in creating societies that are precariously germfree as the result of hubris, germ terrors, or both. French science fiction author Maurice Renard, writing shortly after Wells, also describes a sanitized empire produced by a technologically advanced society. His novel *A Man Among the Microbes* (*Un homme chez les microbes*) details the travels of its narrator, Fléchambeau, who uses a chemical agent to shrink down to the microscale where he discovers a society he terms the Mandarins inhabiting a barren and desolate world. His guide, Agathos, explains that the Mandarins were once overrun by an invasive mushroom species ("the Ooms"), which prompted an increasingly relentless extermination campaign. But like the Martians, they do not stop there: "[the Ooms] were vanquished, but such was the horror of the struggle in which the Mandarin species was almost wiped out that our ancestors resolved to purge the surface of everything that might give rise to similar adversaries. The sterilization of Ourrh was decided."

Fléchambeau discovers that the mechanical labor required to maintain Ourrh's sterility is immense: a nightly procession of machines roving the streets, sweeping and spraying an antiseptic mist with a "crushing cold and chemical odor" that "flowed in all directions, hissing." Meanwhile, the Mandarins rigorously suppress any sign of the mushrooms' return. At the park where living species are preserved, "a high wall surrounded the enormous enclosure. Sentries mounted guard on

[31] Others clearly recognized the human-future theme, as evident in *War of the Worlds* knockoff fictions such as Francis Flagg's *The Machine Man of Ardathia,* which describes a time-traveling alien enclosed in an airtight cylinder who identifies humans as the Primitives from which he has descended some 35,000 years in the future. Likewise, the 1928 short story "Vandals from the Moon" narrates the Earth's invasion by technologically advanced Lunites who are descended from humans, and who like Wells' Martians are vulnerable to earthly microbes (Marius).

all sides and sterilizing boundary-fountains were erected at intervals, each with its flexible hose and its jet. At the slightest alert—I mean, as soon as the tiniest suspect mushroom appeared—the critical location was copiously doused in a pitiless liquid." As in the germfree experiments of Nuttall and Thierfelder and others, the maintenance of a germfree state requires constant supervision, tight control, and mechanical intervention.

Yet ultimately this extermination is shown to be both insufficient and uncontrollable. Believing animals and plants to be a contamination hazard, they confine living species to the park and kill everything else until all that remains is "an arid globe, streaked with hygienic forests, planted with pluviogenic lighthouses and guarded by innumerable surveillance-posts, powerfully armed with antiseptic reservoirs and sterilizing pumps." As Fléchambeau's phrasing suggests, the biological landscape has been replaced by—planted with—the mechanisms of artificial sterility. The Mandarins are living inside a global germfree isolator. And in consequence, they suffer. Fléchambeau observes that Mandarins experience loneliness in their barren landscape and nostalgia for the forests and species they have destroyed. Their suffering is also physiological, as they find that their sterile lifestyle entails a fundamental biological insufficiency. In what seems a direct reference to Pasteur's hypothesis or the weakened animals in Schottelius' and Kijanizin's laboratories, Fléchambeau notes that "excessive sterilization had almost caused all the Mandarins to perish, because of the benign microbes that are necessary to maintain life—which are, perhaps, life itself. They had been obliged to react promptly, a few centuries later, against the excess of hygiene." It is unclear whether this reaction has been effective, since the Mandarin population continues to dwindle.

Renard therefore describes global sterilization as emerging, against reason, from a deep-seated germophobia. His Mandarins seem to satirize Victorian attitudes in their mortal terror of the Ooms, "the frightful, terrible secret that weighs upon Mandarinity." The Ooms provoke a

superstitious dread and shrieking terrors at the sight of any shape resembling a mushroom. Yet Fléchambeau, despite his perception that these episodes are irrational, and despite all he learns about the sufferings of Ourrh and its inhabitants, ultimately reverts to his own, human, germ fears. Upon visiting the park where the last vial of Oom spores is preserved, he tells Agathos that he disagrees with the Mandarins' decision to preserve these last remnants: "*in your place, when you had the Ooms under your bootheel, I would have exterminated them. I wouldn't have left the smallest spore"* (emphasis in original). The irrational compulsion to eradicate, then, is shared across the Mandarin and human worlds.

Other fictions attach more explicit critiques of social dysfunction to germfree technology. This sometimes emerges in the form of classism, or perhaps parasitism, with the attainment of microbial transcendence coming at the expense of a less privileged group. The originating example also comes from Wells, in the germfree gardens of the Eloi in *The Time Machine* (1985). The Time Traveler observes their landscape as follows: "the air was free from gnats, the earth from weeds or fungi; everywhere were fruits and sweet and delightful flowers; brilliant butterflies flew hither and thither. The ideal of preventive medicine was attained. Diseases had been stamped out. I saw no evidence of any contagious diseases during all my stay" (72). In this life of comfort and health, however, all is not well below the surface. The Eloi themselves are characterized by an intellectual lassitude, rendered constitutionally fragile by their chronic lack of struggle. And their Edenic setting, the Time Traveler learns, is literally built on the back of the Morlocks laboring below the surface. As in *The War of the Worlds*, germfreeness comes at the expense of humanity, though here displaced onto another race.

Similarly, in Tim Maughan's short story "Transmission" (2015), freedom from disease is the property of the elite in a post-antibiotic world overrun by infection. The wealthy escape microbial

threats through elaborate airtight suits and their residence in the Shard, an immense sterile facility that appears "like a giant blade has slit open the sky to reveal secret steel and glass scaffolding holding reality together" (25) (Figure 6). The Shard holds together a reality that is the exclusive privilege of the wealthy, deluding them into a sense of aseptic safety while keeping the outer world, with its rampant infection and social unrest, at bay. In this "sterile oasis within the city of plagues," this "sanitised bubble world," the privileged can move freely, secure in their germfree version of reality. Meanwhile, the masses outside huddle together amongst filth and germs with only paper masks and scarves to ward off infection while they, Morlock-like, do the manual labor on which the city depends. The discrepancy between the aseptic elite and the infectious lower classes is the core tension of the story, disrupted when its central character infiltrates the Shard after falling ill in an act of bioterrorism that takes aim not only at the bodies of the elite but also at their alternative reality. Breaching the sterile boundary of their bubble means forcing a confrontation between privilege and lack.

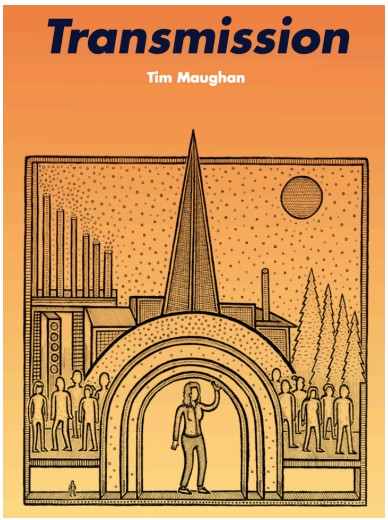

Figure 6. The title page for Tim Maughan's short story "Transmission," featuring a depiction of The Shard with its germfree space about to be infiltrated by a germy intruder.

The most sustained fictional engagement with germfree technology occurs in Michael Crichton's *The Andromeda Strain* (1969). Here, the pursuit of sterilized bodies signifies a wayward

scientific enterprise. Project Wildfire, the massive underground facility housing the US government's laboratories for studying incoming outer space microbes, at first appears to be a resounding endorsement of scientific possibility with its high-powered technology, accomplished scientists, government connections, and an attitude of constructive problem-solving.[32] But these ultimately underscore a deep mistrust of scientific governance and, in fact, "a broadly cynical view of scientific and technological certainty" itself (Woodcock 40). That cynicism manifests in the frequent questioning of scientific authority[33] and especially in Crichton's use of 20th-century gnotobiotic technology, through which the scientists demonstrate an obsession with sterility that contradicts what they know about human-microbial ecology.

The Andromeda Strain draws on and exaggerates the techniques of germfree animal studies, turning them on the scientists in a prolonged decontamination procedure that is required upon entry to Project Wildfire. The scientists progress through five successive levels, each one further underground and more antimicrobially stringent than the previous, featuring full-immersion chemical baths (hexachlorophene, methitol, biocaine, monochlorophin, xantholysin, *and* prophyne), frequent clothing changes, antibiotics, UV irradiation, infrared treatments, and a mandatory sugar-free diet.[34] This extensive treatment is meant to make each "as nearly sterile as possible on Level V," as the clinical microbiologist, Leavitt, explains. "When you think about it," he says, "we've faced up to quite a planning problem here. How to disinfect the human body—one of the dirtiest things in the known universe—without killing the person at the same time. Interesting." Among the last

32 Its legacy in film and fiction over the subsequent decades has certainly largely in that spirit; a number of critics have noted the film version's originating tropes of biosafety labs and protocols so pervasive in outbreak narratives (Ostherr).
33 Priscilla Wald observes that "the term 'Andromeda strain' has become shorthand for sudden devastation caused by mysterious microbes and mismanagement: a clash of ecosystems with cataclysmic consequences on a global scale" (31-2). On Crichton's relentless questioning of the culture of scientific expertise in *Andromeda* and beyond, see (Radin 2019).
34 Kirk notes that the novel is "cast in a nonfictional style accurately incorporating many of the latest innovations in biomedical technology including those for creating microbially isolated environments necessary for the creation of germ-free life" (239).

decontamination steps is a broad-spectrum antibiotic. He explains, "'we're all taking them for the first four days. Not, of course, that they'll do any good,' he said, with the familiar wry, pessimistic look on his face." Leavitt's phrasings here—as *nearly* sterile *as possible, as best we can*, *not that they'll do any good*—suggest a level of biological uncertainty that fractures Project Wildfire's veneer of careful control. For all the careful protocols and procedures, the antiseptic baths and invasive surveillance, there remains a fundamentally unknowable biological remnant within the otherwise purified body, exposing the imperfections of the decontamination protocol.[35]

The novel also calls into question the rationale for decontaminating the scientists in the first place. In standard treatments of biosafety laboratories in film and fiction, as in life, dangerous organisms are contained through stringent quarantine measures so as to secure the organism under study and protect researchers from exposure. In *The Andromeda Strain*, however, the quarantine is applied not to the infectious agent but to the researchers themselves. The strain itself arrives without apparent difficulty in Stage V; the researchers have at their disposal glove boxes, sealed containment rooms, and waldo hands to manipulate the strain and its two infected patients (these, like the baths and clothing changes are also the legacy of germ-free technology). On the other hand, the researchers' own sterility has zero bearing on their ability to do this work or their risk of infection: sterilized or germy, the organism still remains behind its barricade. The extensive decontamination procedure therefore appears as merely another manifestation of Project Wildfire's obsessive surveillance, as a technological procedure undertaken for its own sake.

The desire for a purified human thus signifies a hubristic impulse to assert biological control, even when scientists themselves grasp the risks of such a procedure. This theme is deepened by the novel's staging of catastrophic germfreeness. When the pathologist Burton becomes contaminated

[35] Kirsten Ostherr notes that the film adaptation contrasts the unknowability of the Andromeda strain with the total surveillance of the male body. Leavitt's remarks in the novel reveal the ideal of perfect surveillance to be illusory (163-4).

by Andromeda, he requests treatment with Kalocin, a (fictional) universal antibiotic that selectively kills everything unicellular or smaller, leaving human cells intact. A clinical trial had proven its utility against cancer but with a prohibitive side effect: instant death. Lead scientist Jeremy Stone sees the results as a lesson in the human immune system's adaptation to microbial symbionts:

> If you introduced a new drug that killed all bacteria, you upset the balance and undid the evolutionary work of centuries. And you opened the way to superinfection, the problem of new organisms, bearing new diseases. Stone was right: the forty volunteers each had died of obscure and horrible diseases no one had ever seen before. One man experienced swelling of his body, from head to foot, a hot, bloated swelling until he suffocated from pulmonary edema. Another man fell prey to an organism that ate away his stomach in a matter of hours. A third was hit by a virus that dissolved his brain to a jelly. And so it went.

Like Wells' Martians, the experimental subjects suffer from a disruption of evolutionary co-adaptation that leaves them entirely vulnerable to ordinary disease; they, too, are "rotting like a thing already dead."

The Kalocin digression further complicates the status of the germfree human at the bottom of Project Wildfire. Stone, citing the clinical study, flatly refuses Burton's request for the treatment. Burton too is well aware in the significance of human-associated bacteria; the novel had earlier outlined his belief that "man needed them, and relied upon them." Both researchers grasp the horrific consequences of removing one's microflora, which raises the question: why is Kalocin stashed at Project Wildfire in the first place? And how can they conscionably design and undergo the project's stringent decontamination procedure? Burton is already in Stage V when he makes his request, as thoroughly sterile as scientifically possible. Yet neither he nor Stone is remotely

concerned about the possible biological consequences of asepsis or of their eventual transition back to the microbial world. Kalocin is thus judged to be prohibitively more dangerous than Stage V.

This contradiction can be interpreted in two ways. First, that the potential consequences of germfree humans were simply overlooked in the course of the facility's design in an egregious neglect of the practical applications of Stone's and Burton's own research, with the Kalocin episode undermining Wildfire's façade of rationality. Or second, that Stone and Burton quietly accept the incompleteness of the decontamination protocol, with the microbial remnant Leavitt references providing a protective role that makes Stage V safer than Kalocin; in other words, they survive because of the imperfection of the decontamination process they reverence.

Either way, the novel identifies the pursuit of germfreeness as belonging to a broader politico-scientific derangement. Gnotobiotic technology therefore functions just as it has historically in fiction: to illuminate the intellectual deficits intrinsic to germfree fantasy. Stone himself recognizes this, in an echo of Wells' Martians and their hypertrophied brains:

> There were times when he saw man, with his giant brain, as equivalent to the dinosaurs. Every schoolboy knew that dinosaurs had outgrown themselves, had become too large and ponderous to be viable. No one ever thought to consider whether the human brain … was not analogous. Perhaps the human brain had become a kind of dinosaur for man and perhaps, in the end, would prove his downfall.

As its own lead scientist recognizes, the Project Wildfire team is just as stymied by reason as are the Martians and Eloi, Mandarins and Shard residents. In each case, germfree spaces threaten the survival of the human(oid) bodies they contain and in doing so reveal the failures of societies caught up in the quest for biological transcendence.

3. The World without Microbes

The same would also be true at a much wider scale. In the tradition of subtractive reasoning through which human-microbial symbiosis is described has run a parallel thought experiment that extends the logic of germfree spaces to the planetary scale. In a world constituted by microbial life, its absence means death—an insight developed through elaborate imagined scenarios of global destruction. These scenarios are often formulaic, suffusing scientific and popular scientific writing with recurring images of individual and global suffering that together make visible diverse roles of unseen life. They are also explicitly apocalyptic, deploying the science fictional mode in order to bring about a reader's revelation as to the stakes of global microbial ecology.

Like gnotobiology, this speculative lineage originates with Pasteur, specifically with his work on fermentation. Though best known for his studies of beer, wine, and spoiled milk, he consistently connected their fermentation to the process of decomposition in a global ecosystem. He understood microbes as reshaping organic matter at all scales, convinced of what he termed "the immense physiological role of the infinitely small in the general economy of nature" (Pasteur 1862 p.3)

For Pasteur, life in a world without microbes was impossible. In a paper read at the Académie de Médicine in 1875, he outlined the successive decompositions through which a vat of grapes would become first juice, then wine, then vinegar, and so on until only an empty vessel remained with a few inert minerals dusting the bottom, at which point "the mineral substances are ready to return to the soil, the organic matter has passed into the air, and when all shall have become dry the spores of the moulds and the cysts of the infusoria will be borne away upon the wings of the wind, to recommence, elsewhere, their work of life and of destruction of life" (Pasteur 1875 p. 719). Microbes, that is, make possible the timeless cycle of life, destruction, and new life.

Pasteur was prone to illustrating the reliance of life upon microbes by imagining their disappearance. In an 1862 letter to the Minister of Public Education, he had observed that the decomposition of dead plants and animals "is one of the necessities of the perpetuation of life." He wrote,

> If the remnants of dead plants and animals were not destroyed, the surface of the earth would soon be encumbered with organic matter, and life would become impossible because the cycle of transformation . . . could no longer be closed.
>
> It is necessary that the fibrin of our muscles, the albumin of our blood, the gelatin of our bones, the urea of our urines, the ligneous matter of plants, the sugar of their fruits, the starch of their seeds ... be slowly resolved to the state of water, ammonia and carbon dioxide so that the elementary principles of these complex organic substances be taken up again by plants, elaborated anew, to serve as food for new living beings similar to those that gave birth to them, and so on ad infinitum to the end of the centuries. (Pasteur 1862)

In this letter, germfreeness interrupts the *ad infinitum* work of organic matter's renewal. The fleeting prospect of a world without germs, burdened by accumulated corpses as life slowly diminishes, is presented here in muted but startling form.

Paul de Kruif's *The Microbe Hunters* detects the apocalyptic scenario lurking in Pasteur's invocation of an amicrobial Earth:

> Like a great bird Pasteur spread his wings of fancy and soared up to fearsome speculations—he imagined a weird world without microbes, a world whose air had plenty of oxygen, but this oxygen would be of no use, alas, to destroy dead plants and animals, because there were no microbes to do the oxidations. His hearers had nightmare glimpses of vast heaps of carcasses choking deserted lifeless streets—without microbes life would not be possible!

De Kruif's describes a Pasteur borne away on the back of fancy, accessing from the fearsome heights of imagination a privileged glimpse of the nightmare of a world without microbes.

Pasteur's successors would follow his lead, envisioning catastrophically barren, antiseptic worlds.[36] One of the nightmare glimpsers de Kruif described was almost certainly Henry S. Gabbett, M.D., whose article in *The Living Age*, referenced above, is the earliest elaboration of the world without microbes thought experiment that I have been able to trace. His article, in its efforts to counter the dominant perception of germs as "maleficent," argues that microbes are in fact largely "useful workers in Nature's laboratory, so useful, in fact, that they are quite indispensable. A germless world would not be worth living in" (307). Gabbett's ensuing discussion appears influenced by Pasteur. However, it is to fictional rather than scientific discovery that he turns: "The active imagination of Mr. H. G. Wells has lately discovered a germ-free world in the planet Mars… But he does not attempt to picture the condition of things in the germ-free world itself. Let us try for a moment to imagine the state of the earth deprived altogether of this form of life" (309). For Gabbett, the utility of microbes is comes into view through the imagination more than through scientific arguments. His task is to build on Wells' precedent through the labor of *picturing* and *supposition,* by which means he invents his own fictional device, a universal germicide: "Suppose, then, that air, water, soil, animals, and plants have all been thoroughly *sterilized* in the bacteriological sense; suppose that by the universal application of an ideally perfect germicide every microbe has been killed, while higher living things remain unharmed" (309).

Aiming to dispel the latent germ terrors of his generalist audience, Gabbett first acknowledges the positive effects of missing microbes: "First, we observe with gratitude that we

[36] Such imaginings were almost certainly influenced by other contemporary conceptions of the microbial status of the planet (e.g., Ehrenberg's "microgeography" which envisioned geological features as the result of microbial action). Pasteur, though, was the first to imagine the world in the absence of microbes.

have done with a large number of diseases, acute and chronic, affecting beasts and men." Anthrax, glanders, scarlatina, measles, leprosy, plague, infected wounds and even food poisoning—gone! Gabbett allows a rush of wonder at this prospect: "it would almost seem that everybody should be satisfied, except the bacteriologist, whose occupation is done" (310). But the pivot that follows dispels such optimism at once. He writes, "very soon we begin to miss some things in our germless world." He notes that the fermentation of foods and alcohol would cease and higher organisms suffer from impaired digestion. Next would come losses of the textile and fertilizer industries and eventually agriculture, which would become impossible without soil nitrification. Life itself would be threatened, for "the activity of these lowly forms is a condition essential to the continuance of life on the earth" (311). Echoing Pasteur, he asks: "If such processes did not take place, whence would be derived the materials for the construction of successive generations of animals and plants? … If these decompositions were to cease, if animals and plants were to remain incorruptible after death, how can we escape the conclusion that sooner or later the supply of such available elements must be exhausted, and life itself must come to an end?" (311). In expanding Pasteur's more subtle speculations, Gabbett's article recasts scientific thought as fiction in making its argument for the absolute necessity of microbes to life on Earth. A contemporary response suggests the efficiency of his strategy. "Is a germless world desirable?," asked an 1899 summary in *Dental Digest*. "Dr. Gabbett's question answers itself … few of his readers would vote to have this world of ours sterilized, even to gain immunity from leprosy and small-pox" ("Is a Germless World Desirable?" p. 635).

In subsequent years, the imagined (im)possibilities of a germfree world circulated widely in scientific discourse. An article published in *St. Paul Medical Journal* in 1902 stated that "even by the general public a world without bacteria is scarcely to be imagined" (Wesbrook 17). And a book on

soil fertility in 1925 noted that "it is hard to conceive of our living in a world without bacteria" (Greaves and Greaves 17). In these and other instances, the *imagining* or *conceiving* of a sterile world reveals it to be simply inconceivable.

Within the confines of the strictly fictional—the overtly speculative—the imagination of a germfree world would be carried forth in the same form and function, but growing more detailed. Perhaps its most elaborate and prominent version arrived in 1945, in the epilogue to *Microbes of Merit*, a popular science book by American bacteriologist Otto Rahn. The book as a whole celebrates the diverse roles of microorganisms in human life, including fermentation, industry, agriculture, and more. The epilogue emphasizes those roles via imagining their absence. Rahn undertakes the work of imagining the scarcely imaginable: "Let us realize the good and bad features of microbes by visualizing a world without them. Let us imagine what would happen if suddenly each and every microbe on earth were killed." Like Gabbett, Rahn effects this scenario through a magical intervention, in this case, "a collision of the earth with the tail of a comet which contains a mysterious gas killing all microbes without doing any damage to plants, animals and man" (269). His version, while more detailed and catastrophic, follows the same formula as his predecessor's.

Rahn describes an initial, joyful realization of life's improvements: "a sigh of relief" upon the sudden resolution of bacterial diseases, and the hope of a new world in which "we can change the tuberculosis hospitals to old people's homes, and the leprosy colonies to public bathing beaches. Quarantine and vaccination exist only in old fairytale books, and sounds like medieval torture to the new generation" (269). Food would keep indefinitely, and the need for preservation efforts disappear. Rahn exclaims, "It sounds almost too good. What an easy life" (270).

But disaster follows; the antimicrobial comet quickly reveals the popular association of microbes with disease to be short-sighted. His epilogue lays out a series of progressive, increasingly

impactful problems. Initially, he suggests, simple problems like the inability to ferment foods could be easily remediated by cheerful human ingenuity. But cascading challenges would soon outstrip humans' ability to compensate. For instance: cows' inability to digest grass would require farmers to switch to corn and alfalfa feed, triggering a soil-nitrate crisis without bacterial nitrogen fixation, which would then necessitate a shift to industrial nitrogen fixation, requiring massive electrical consumption that would cause humans to abandon agriculture entirely in remote regions. And so on. Rahn predicts macroscale geographical disaster: "We will live to see the Rocky Mountains studded with dead trees which will sooner or later be destroyed by unavoidable forest fires. We may not live long enough to see all the fertile soil, which is no longer held in place by grass and tree roots, being washed into the creeks, so that only bare rock remains where Yellowstone Park used to be" (272). And alongside these, clogged rivers, undrinkable water, and humans dying of avitaminosis. The world, in essence, would become a global germ-free incubator with all the deprivations and death described in the early history of gnotobiology.

Rahn is somewhat more optimistic than Pasteur and Gabbett about the outcome of this aseptic world, taking a shorter temporal view that stops before the world begins running out of the elements needed to generate new life. And so, he predicts, at least for technologically advanced societies, life could trudge on: "The prospect of life without microbes … will seem a strange life to us who take the cooperation of microbes for granted, and it will be a hard life, but probably we can make it" (274). He emphasizes once more that a life without disease is not worth living, concluding: "Although we will be safe from any contagious diseases for ever, life without microbes may seem hardly worth living to most of us. Let us hope that we never collide with the tail of such a comet" (274).

While Rahn's epilogue was aimed primarily at a germophobic public, it was also influential for more specialized practitioners in science and medicine. The book, and particularly its imaginative epilogue, was highlighted in *New York State Journal of Medicine* and *The Organic Farmer*, among others. Within microbiology, Dutch scientist A. J. Kluyver hailed it as a milestone in his 1953 Leeuwenhoek Lecture at the Royal Society. Kluyver credited Rahn with "a new appraisal of the microbe. Far from being man's enemy we have to accept it as an indispensable element of living nature, without which neither mankind, nor any other higher organism—animal or plant—could subsist on earth… The disappearance of the microbe from man's horizon would mean an irreparable loss" (152).

The legacy of imagined germfree worlds has continued among scientists into the present. In 2006, microbiologist Moselio Schaechter posed this "Talmudic question" on his blog at the American Society for Microbiology's website: "What if all the bacteria and archaea on Earth decided to go on strike and stop their metabolism all at once? Which of the global cycles of matter would be affected first? How long would it take for life as we know it to come to a stop?" Schaechter's question is consistent with the tradition of absence narratives I have been discussing. Like his predecessors, he implies a temporal unfolding of catastrophe resulting in the final cessation of familiar life. User david lipson responded in this spirit by pointing to the global nitrogen as critical, with photosynthesis stopping after a week, evergreens dying within a year, and humans lingering for hundreds of years in an atmosphere of slowly increasing greenhouse gases (provided, of course, "an everlasting supply of canned pork and beans"). Alternatively, he suggests plants might be kept alive but only (as in Rahn) given the availability of "absurdly huge, planetary fertilizer inputs."

Despite the drama of the scenarios they narrate, the prospect of life in a world without microbes, which might be apt fodder for fiction, has persisted primarily within the writings of bacteriologists and physicians. The thought experiment has structured scientific thought and

education from the start, almost always presented as a corrective to the impulsive dream of life beyond germs. These extended narratives of the world without germs all operate within the apocalyptic mode through which science fiction has traditionally critiqued, for example, technological progress. They offer a means of reexamining germophobic impulses by announcing themselves as fanciful speculations through which to explore the consequences of microbicide. As Lorenzo Servitje has written, contemporary discourses of antimicrobial apocalypse operate in the same way, defamiliarizing the historical events fostering resistance so as to encourage us to "rethink not only the present, but the past and future of antibiotics, both for themselves and for Western culture more broadly" (318).[37] In both categories of apocalypse stories, the human relationship to microbes is presented as explicitly fictional, so as to expose the underlying logics of germophobia and antibiotics by scaling it up to its widest implications. Missing-microbes stories, in detailing the consequences of *hypothetical* planetary sterility, allow readers to reevaluate real mistakes of the past and recognize the need to intervene in the trajectory of the present.

The narratives discussed above are the most elaborate instances of the missing-microbes thought experiment, but it has also persisted in speculative gestures on a smaller scale. These reflect the legacy of germfree disaster scenarios within science even though they generally do not announce themselves as science fiction. In the range of settings I discuss below, the thought experiment serves the same purpose of revealing the inseparability of human, microbial, and planetary life. They surface especially within the educational imperatives of science: its communications to children, to readers of popular science, and to its own students.

[37] Nerlich also discusses the didactic value of the antibiotic apocalypse's discursive register, tracing its manifestations in healthcare and microbiology as deepened through resonances with climate disaster.

The delineation of a germfree world trope is explicitly didactic when it functions as an illustrative device for children. A representative example is *Getting Acquainted*, an elementary health textbook published in 1954 (O'Keefe et al.).[38] It follows the established formula in narrating a group of schoolchildren dismayed to learn that their friend is home sick with scarlet fever and his sister quarantined. As usual, the positives come first. One child wonders, "Wouldn't it be nice if we didn't have any germs at all? Then we wouldn't have to worry about Dick being sick or Faye not playing with us" (49). Other children imagine that food wouldn't spoil and hand washing would become unnecessary. "Wouldn't this be a wonderful world if there were no germs?" they ask their teacher (49). She responds by explaining microbes' various uses in cooking and agriculture, prompting one student to conclude that "germs are sometimes hard to live with, but we cannot live without them" (50). The vignette is self-reflexive in its educational import: a story about teaching that in turn shows adults how they might teach about microbes.

In the domestic space, too, readers (mainly housewives) were compelled to consider the contradictions of their exterminative approach to microbes. For instance, in a 1968 essay on communicable diseases published in the 1968 collection *Good Health: A Guide to Preventive Medicine*, Douglas Gordon wrote that a generation raised on the belief that germs are "something akin to works of the devil to be avoided at all costs" have grown up aspiring "to create a 'germ-free' environment" sometimes leading to "extreme measures which have made home life a trial by hygienic ritual, and have limited life outside the aseptic home to social contacts considered suitably fastidious and clean. All this is taking great pains to accomplish the impossible" (198). Douglas goes on to demonstrate that "there is no such thing as a 'germ-free' world," noting that agricultural and

[38] Other instances abound. See, for instance, Discovery Channel School's handbook *Bacteria A-Z,* which invites children to "imagine waking up one morning to a world without microbes." It follows the usual contours of the thought experiment before landing on the comment that "within a few weeks we would be up to our armpits in lawn clippings, banana peels, dead animals, and so forth"—undoubtedly a compelling image for young kids (*Bacteria A-Z* 15).

horticultural systems would fail in the absence of microbes. He advocates instead for a "sensible approach" of limiting pathogens without trying to destroy them wholesale. Likewise, the home economics magazine *Housecraft* in 1972 reminded its readers that "some bacteria, for instance the lactic acid bacillus which produce the obvious cream of milk, are helpful to us. We cannot have a living world without bacteria" (*Housecraft* 24).

And in higher education, new generations of microbiologists are often greeted with the suggestion that life without microbes is impossible. Introductory microbiology textbooks commonly open with a segment outlining the diverse roles of microbes in the human body and global ecosystem; these often include versions of the world-without-microbes thought experiment, though generally in more terse form than the examples above. For example, in 1950 bacteriology professor C. E. Clifton opened his textbook *Introduction to the Bacteria* with this statement: "On all sides, microbes, or microorganisms, surround us and make felt their influence for good or evil. Some are benefactors, and without their activities in nature, life as we know it could not exist; others are agents of infection and death" (1). Even bacteriologists in training would have easily recognized the "evil" bacteria Clifton describes as surrounding us on all sides. Clifton heads off any latent germophobias with the brief but familiar sentiment that life cannot exist without the bacterial benefactors.

Microbiology textbooks also commonly recruit the missing-microbes trope in discussions of fermentation and decomposition—unsurprisingly, as this is the context of Pasteur's original thought experiment. Clifton borrows Pasteur's formulation, asserting that without decomposition "enormous quantities of carbon would be stored in the dead bodies of plants and animals and thus lost to the cycle. Microbic activity is one form of insurance that, in the natural history of events, there will be no major blockage of the carbon cycle as a result of the retention of carbon in organic

molecules" (341). Pasteur goes uncredited here, and the language is undramatic, perhaps suggesting that the formulation was had become familiar within bacteriology.

Clifton's suggestion of "major blockage" in the course of natural history is broadly recited. In their introductory textbook *Bacteriology,* from 1923, H. W. Conn and Harold J. Conn observed that synthetic and destructive processes "are diametrically opposed to each other; yet one is as necessary to life as the other. Life is possible in the world only as long as these two processes are in balance" (67). They continue by arguing that the decomposition of green plants is absolutely necessary to life on earth:

> Were there no means of reducing these into simple forms, they would accumulate until the face of the globe would be covered by dead vegetation to the exclusion of everything else… For the continuation of life, the analytical processes are just as necessary as the synthetic, since either one of them if continued alone would soon bring all life activity to a stop. The importance of the green plants in building up foods for animal life is generally understood and appreciated; but the equal necessity for the opposite process—destruction—is less commonly realized. (69).

It is through just these scenarios that the *less commonly realized* becomes realized. In repeatedly invoking the inevitable collapse of an aseptic world, Conn and Conn render visible the contributions of bacteria. In instances like these, microbiology has continually reasserted the contingency of planetary life upon the activity of the microbial world. Though more concise and less fanciful than the scenarios elaborated by Rahn and Gabbett, perhaps because in their professorial roles bacteriologists are more reluctant to identify themselves as participating in the work of imagination, these too call forward the latent catastrophe of germfree fantasy.

The educational utility of an imagined the world without microbes is most apparent in popular science. As in the formative examples of Gabbett and Rahn, examples tend to be colorful and dramatic and are widely distributed from the 1950s to present. They are generally found in texts authored by scientists, reflecting the depth of missing-microbes thinking within scientific discourse, suggesting its status as a go-to illustrative device uniquely positioned to dispel the public's dream of life without disease. Ranging from terse aphorisms to more elaborate narratives, they can be grouped according to their imaginative scope.

The narrowest scenarios make limited claims that without microbes, particular things would not be possible. Microbiologist Bernard Dixon, for instance, in his 1976 book *Magnificent Microbes* repeatedly bemoaned the loss of craft fermentation methods in as food production grew more industrialized. "We do not only wish to produce pure alcohol," he writes, appalled at the thought of a microbeless drink, "we desire the glorious fruits of microbial alchemy" (87). Similarly, he describes a recent effort to produce cheese without microbes as a culinary disaster, for it "had no cheese flavour whatever" (93). For Dixon, these examples illustrate that "no individual eater or imbiber, no cuisine, is independent of the busy and ubiquitous microbe…" (98).

More common are scenarios that emphasize human suffering in a germfree world. Stanley E. Wedberg writes in the introduction to *Microbes and You* (1954) that "the tremendous good that [bacteria] accomplish for mankind should not be overlooked. The statement has been made that were it not for microbes, you and I would not be here. That is a rather strong assertion, yet there is plenty of evidence to add weight to such a contention" (3). The source of the statement he alludes to is not given but his phrasing grants the concept an urban-legend quality, reflecting a developing consensus. That sentiment is reprised, for instance, in Jeanette Farrell's *Invisible Allies: Microbes That Shape Our Lives* (2005), in which the author asserts that "Microbes were around for billions of years

before humans and will likely continue to thrive long after we pass away. All of this is, in fact, some great comfort, as we could certainly not survive without them. They are the recyclers of the planet, invisibly keeping life going, and they are silent partners in our bodies…" (143-44).

At a wider scale, world-without-microbes moments emphasize the contingency of life, broadly speaking, upon the activity of microbes. Wedberg's book invokes a world overrun by "the vast accumulation of ancestors, plant and animal, [that] would soon leave little room for the living," culminating in life itself "grind[ing] to a creaking halt" (3). In 1976's *The Microbes, Our Unseen Friends,* Harold W. Rossmoore imagines a world without microbes in which "since the dawn of life we would have been accumulating the detritus of death" (131). Likewise, John Postgate writes in *Microbes and Man* (1969, 1986) that microbes "are of transcendental importance in the terrestrial economy, because without them higher organisms would rapidly cease to exist" (22); he observes later that "if it were not for their activities we should all be up to our necks in an appalling morass of the detritus of human activity" (184).

At its most far-reaching, the germfree imaginary of popular science leaves humans behind altogether, envisioning the planet itself dying without microbes. In a 1996 *New York Times* interview, bacterial phylogenomicist Carl Woese illustrated the significance of terrestrial organisms as follows: "It's clear to me that if you wiped all multicellular life forms off the face of the earth, microbial life might shift a tiny bit… [but] if microbial life were to disappear, that would be it – instant death for the planet" (Woese). Woese's Earth becomes a living entity, teeming with the microorganisms on which its processes depend and the loss of which is figured as a planetary death. An apocryphal quote by Lynn Margulis—"the moon is what our planet would look like without microbes"—figures microbial absence in similar terms (qtd. in Sachs, 10). These examples compress the vast

contributions of bacteria into a singular global catastrophe, with the planet itself as imperiled by germophobia: destroy the microbes, destroy the world.

This abundance of instances suggests a thought device well entrenched within scientific discourse. As such, it has inextricably shaped not only the public consciousness of microorganisms in response to germophobic impulses but also the direction of scientific discourse itself more narrowly. As I argue in the remainder of this chapter, scientists' own immersion in germfree catastrophe narratives has, whether consciously or not, structured the emergence of microbiome discourse and its central claim that we simply cannot do without our microbiota.

Scientists had already recognized the interlinkage of germfree thinking and scientific practice. In 1963, a panel of accomplished scientists met in a London conference on the scientific future of humanity (transcribed in Wolstenholme). Virologist Hilary Koprowski introduced the familiar theme of a germfree future as fundamentally flawed, speculating that "if a universal antibiotic became available in the future and were used for prevention and therapy of human infections on a mass scale, a major disaster would befall the human species. There is no greater nightmare to dream about the future than the creation of a germ-free man" (204). Koprowski's speech, that is, sought once more to transform the dream of germfree life to nightmare.

In response, recognizing that the world-without-microbes conceit has persisted for a reason, bacterial geneticist Joshua Lederberg countered that the power of the thought experiment lay not in its material practicability but in its thought value. He argued that "we have heard of such abstractions as a germ-free world, indefinite life-span, and the intelligent self-reproducing machine. Each of these is quite possibly not attainable in its full form, but it doesn't need to be so in order to be well worth thinking about. These abstractions pose problems that we have to deal with either in emulating life or in setting up appropriate social dynamics in the clearest possible form" (234).

Concerning the germfree world in particular, he observed: "The complete description of what would be wrong with a germ-free world, how to go about achieving it, how it could be maintained and what the imbalances are that might flow from it, might be much more inter[e]sting and provocative than any of the partial steps towards it." He listed a sequence of questions that might follow from taking seriously the hypothetical possibilities of a germfree world: "What fundamental basic limitations would there be in maintaining a germ-free world and what would be its danger? The implication is that it would be dangerous because we would be extremely vulnerable to the introduction of a single micro-organism which otherwise might not be pathogenic. Why is it pathogenic under those circumstances? Is it only necessary to maintain some reasonable level of activity of the reticuloendothelial system in order to have a ready response?" Ultimately, he concluded, "it is only by pushing these abstractions to the limit that we are going to be irritated into thinking about questions that are a little bit more general than the immediate ones of today" (234-5).

Lederberg thus recognized both the depth of the missing-microbes thought experiment and its value for driving forward scientific thought. Like Pasteur, he saw the germfree condition as intellectually productive even if biologically unsustainable. It is just this sort of productive abstraction that has shaped the microbiome era's engagement with germfree life both in science and in the public eye.

4. Missing Microbiomes

The thought of a germfree world is more than mere abstraction, however. While Lederberg's assertion that the possibility is a useful fiction, a "provocative" thought experiment, germfree spaces on smaller scales—both real and imagined—have had a tangible material influence on the unfolding of microbiome research in the past two decades.

It was Lederberg himself who, nearly four decades after that London conference, would coin the term *microbiome*. Was he thinking of the useful abstraction of a germfree world when he proposed an accounting of "the ecological community of … microorganisms that literally share our body space and have been all but ignored as determinants of health and disease" (Lederberg)? Did the intellectual heritage of gnotobiology prompt him to present his neologism in relation to the widespread *ignoring* of microbial significance, as missing-microbes narratives have always done? Perhaps; perhaps not. But what is abundantly clear is that as the microbiome concept came into being in the early years of the 21st century, it was inseparable from both the material and the imaginative legacy of germfree animal research—"irritated" into being in part through the rich heritage of germfree speculation. Microbiome discourse has continually turned to the impossibility of germfree life as a thing already known, recruiting its narratives and tropes into the argument that life without germs is simply impossible. Contemporary versions are updated, however: they are less fully speculative, also entailing an argument for actual antiseptic threats that pervade the modern world and set our microbiota at risk.

Contemporary microbiome discourse is pervaded by aphoristic visions of the world without microbes, in line with the range of precursors I described above. Popular science writer Melvin A. Benarde, for instance, in the 2007 book *Our Precarious Habitat ... It's in Your Hands,* rejects the possibility of a microbeless world on the grounds that humans simply cannot do without their favorite fermented foods. Could we subsist without butter, bread, coffee, tea, and cocoa? he asks, before concluding with a flourish: "life without microbes; never" (79). More commonly, authors turn to the familiar prospect of the germfree world. Microbiologist and popular science writer S. R. Joshi, in *Microbes: Redefined Personality* (2007) writes that "without microbes in the soil there would be no agriculture; without microbes in our cells processing oxygen, we would not be able to breathe"

(66). Helga Zelinski writes in 2014's *Microbes, Mindcrobes* that "we cannot live without them… this whole world would be filled with dead bodies piled up over millions of years. We would be living in a giant graveyard." And science writer Idan Ben-Barak states simply: "Life on Earth relies completely and utterly on the existence and actions of microbes" (119).

These snippets, and the countless others that populate microbiome popular science, are echoes of the past, evidence of microbiology's continuing debt to the germfree imagination. Yet in the context of the books in which they appear, contemporary visions of the world without microbes are less hypothetical than their historical precedents. They are intended to comment on a present in which the aseptic existence is troublingly near at hand. Joshi, for instance, continues after his imagination of a world and body suffocating without microbes: "The threats are real." The war on microbes threatens human existence; the key, he writes, is not eradication but "a microbial balance of power" (66). These contemporary visions, that is, are meant to halt the arrival of a giant graveyard, or a microbeless cuisine, or the end of life itself. They operate as a warning for a trajectory into which we are slipping.

The most sustained example is a modern-day scientific tale of microbes gone missing from a 2014 paper titled "Life in a world without microbes," published in the high-profile, open-access journal *PLoS Biology*. Microbial ecologist Jack A. Gilbert and biologist Josh D. Neufeld begin with a nod to Pasteur, taking a modified version of his 1885 hypothesis as an epigraph: "*'Life would not long remain possible in the absence of microbes.' — Louis Pasteur."* This version of Pasteur's prediction is a widely circulating translation dating back decades, one that subtly shifts its author's circumspect prediction into a more urgent register. Without the specific context of the laboratory chicken, *"la vie"* is made to stand for all life, globally. Further, the translation shifts the verb, rendering "*deviendrait impossible"* as "would not long remain possible" rather than the more accurate "would become

impossible." Together, these modifications convey a sense of global life rapidly expiring. Pasteur's gnotobiotic animal thus becomes a proxy for the gnotobiotic Earth: the article outlines the devastating global impacts that they see as foreshadowed in his founding hypothesis.

The paper is presented as an apparent challenge to Pasteur's hypothesis, opening with a response to the epigraph: "Or would it?" The authors also situate their thought experiment as a response to the missing-microbes speculations that have proliferated since Pasteur: "How many times have we started proposals, manuscripts, or presentations with compelling statements about the critical roles that microorganisms play in sustaining life? How often has the possibility of a world without microbes been explored in our introductory microbiology classes?" The authors emphasize their subtractive reasoning as didactically useful in "promot[ing] discussion about the value of microbial services" (1)—exactly as their predecessors have always done.

In the vein of Gabbett's "ideally perfect germicide," Rahn's comet, and Schaechter's microbes-on-strike, the authors invent an "antimicrobial wand" as the precipitating disaster that unleashes the cascading devastations of asepsis.[39] In line with the established formula, they begin with the dismissal of germophobic aspiration, observing that a sudden improvement of health would be "welcomed, initially, by jubilant media headlines announcing a global microbiological 'miracle'" (3). Such celebrations would, of course, be short-lived due to rapidly escalating catastrophes confronting climate, the food supply, and a crisis of un-decomposition. They project eventual ecosystemic and biogeochemical collapse, followed by "complete societal collapse … linked to catastrophic failure of the food supply chain. Annihilation of most humans and nonmicroscopic life on the planet would follow a prolonged period of starvation, disease, unrest, civil war, anarchy, and global biogeochemical asphyxiation" (3).

[39] Indeed, they discuss Schaechter's "Talmudic Question" explicitly and use david lipson's response, discussed above, as the starting point of their analysis.

The paper's initial challenging of Pasteur thus ends in a rather qualified disagreement: "Would life be extinguished…? Not immediately, not all life, and potentially not for a long time." They predict that life would trudge on even if all microbes were eliminated: "we argue that humans could get by without microbes just fine, for a few days.* Although the quality of life on this planet would become incomprehensibly bad, life as an entity would endure."

And so even while the authors disagree with "the usual rhetoric… that life as we know it would collapse, and eukaryotic life would cease to exist," life without germs is still largely unthinkable. The point becomes most clear in the paper's final moment, with the asterisk corresponding to the quote in the paragraph above. They stipulate: "*If we do include mitochondria and chloroplasts as Bacteria, as we should, then the impact would be immediate—most eukaryotes would be dead in a minute." In that final note (dead in a minute!) is revealed once again the power of the subtractive imagination to reveal the utter contingency of life on microbial activity.

The real story here, of course, is not the question of life's enduring but rather the instructive possibilities of apocalyptic narrative. The fictionality of the scenario is asserted more forcefully in a video adaptation developed by science journalist Ed Yong in collaboration with Gilbert. Over scenes of devastated landscapes, rotting produce, piled up livestock carcasses, Dracula castles, and zombies, Gilbert exclaims, "catastrophic ideas are exciting! Everyone loves a disaster movie!" (Yong) (Figure 7).

Figure 7. Ed Yong (top left) unveils the "terrifying thought experiment" latent in Gilbert and Neufeld's paper (Yong).

Elsewhere, as the viewer catches glimpses of vultures, dead fish, and zombies, he laughs, "It's a great thought experiment. It's not happy, but—I love zombie movies. And disaster movies. And I think we naturally want to see what would happen if all of this normalcy decayed." Gilbert's celebration of catastrophe suggests the use of fiction as a lure, drawing audiences to the spectacle of unfolding disaster. "The world is dying," Gilbert proclaims. "It's not just humans killing each other, but the world is dying, the oxygen is running out. It's global death." Cut to an image of a sea of skulls: the world buried in the detritus of life.

For Yong and Gilbert, as in microbiome discourse broadly, the apocalypse is more than merely an exercise in the imagination. It is also an argument for apocalypse in the making, an assertion of microbiomes at risk in an increasingly aseptic world. With the explosion of American microbiomania has come the mainstreaming of germfree precarity. No longer relegated to fringe fiction or scientific hypotheticals, germfree suffering is presented as a material reality in our world. It carries the argument that modern life is, in fact, driving toward asepsis; germfree catastrophe looms.

As the video draws to a close, Yong emphasizes the didactic value of the missing-microbes thought experiment along with a warning. Speaking from within the world of the narrative, he says, "I miss my microbes." But he is also speaking from within our present world, one within which microbes are still present but imperiled. Gilbert answers, "I miss them too. In fact, the *whole world* is missing them right now." This conversation reveals a microbiome-era deformation of the missing-microbes speculation in which what is at stake is not only humans' appreciation for the diverse roles of microbes but also the material existence of microbes and humans at a time of asepsis-in-progress. Moments later, the dialogue concludes the film with the following:

Yong: And this particular horror movie has no sequel.

Gilbert: There's no sequel. This is game over.

Yong: Microbes are important.

Gilbert: Without them, we're doomed. Literally.

Yong: So rejoice in your microbes ... treat them with respect, and they will return the favor.

The imaginative catastrophe of a sterile world is presented here as a material threat, reversible with a respect and rejoicing in the microscale world upon which our very existence depends.

Across microbiome discourse, as the following chapters will show, the warning imparted by Yong and Gilbert becomes more dramatic and explicit: that we are living in a world materially striving toward asepsis, that we risk transforming ourselves into Martians, Eloi, Mandarins in the maniacal quest to conquer microbial life. The next chapter will demonstrate how the microbiome era has widely articulated the dependency of human life on microbiota through frequent turns to germfree animals and stories of humans bound in gnotobiotic isolators as figures for the culmination of germfree fantasy. The suffering of germfree life is an expression of the didactic impulse outlined in this chapter: that through witnessing the endpoint of antibiosis, readers are directed back to an

appreciation of all that microbes make possible. The suppressed biodiversity of the modern microbiome as a site of nostalgia, loss, and grief.

Without microbes, we would suffer; without microbes, *we are suffering*.

Works Cited

Bacteria A-Z. Discovery Channel School, 1999.

Benarde, Melvin A. Our Precarious Habitat ... It's In Your Hands. Wiley, 2007.

Ben-Barak, Idan. The Invisible Kingdom: From the Tips of Our Fingers to the Tops of Our Trash, Inside the Curious World of Microbes. Basic Books, 2009.

Bogdanow, E. A. "Über die abhängigkeit des wachstums der fliegenlarven von bakterien und fermenten und über variabilität und vererbung bei den fleischfliegen." *Archiv für anatomie und physiologie, Physiologische abteilung*, 1908, pp. 173–200.

Clifton, C. E. *Introduction to the Bacteria*. McGraw-Hill, 1950.

Cohendy, Michel. "Expériences sur la vie sans microbes." *Annales de l'Institut Pasteur: Journal de microbiologie*, pp. 106–37.

Conn, H. W., and Harold J. Conn. Bacteriology: A Study of Microorganisms and Their Relation to Human Welfare. Williams & Wilkins Company, 1923.

Crichton, Michael. *The Andromeda Strain*. Vintage Books, 2012.

de Kruif, Paul. *The Microbe Hunters*. Harcourt, Inc., 1926.

Dixon, Bernard. *Magnificent Microbes*. Atheneum, 1976.

Duclaux, Émile. "Sur la germination dans un sol riche en matières organiques, mais exempt de microbes. Note de M. E. Duclaux, présentée par M. Pasteur." *Comptes rendus hebdomadaires des séances de l'Académie des Sciences*, vol. 100, no. 1, 1885, pp. 66–68.

Farrell, Jeanette. *Invisible Allies: Microbes That Shape Our Lives*. Douglas & McIntyre Publishing Group, 2005.

Flagg, Francis. "The Machine Man of Ardathia." *Amazing Stories*, vol. 2, no. 8, Nov. 1927, pp. 798–804.

Gabbett, Henry S. "Beneficent Germs." *The Living Age*, Volume IV, Sept. 1899, pp. 307–11.

Gernsback, Hugo. *Ralph 124C 41+: A Romance of the Year 2660*. 2nd ed., Frederick Fell, Inc., 1950.

Gilbert, Jack A., and Josh D. Neufeld. "Life in a World without Microbes." *PLOS Biology*, vol. 12, no. 12, Dec. 2014.

Gordon, Douglas. "Communicable Disease." *Good Health: A Guide to Preventive Medicine*, edited by Victor H. Wallace, F. W. Cheshire, 1968.

Gordon, Jeffrey I. "Honor Thy Gut Symbionts Redux." *Science*, vol. 336, no. 6086, June 2012, pp. 1251–53.

Greaves, Joseph Eames, and Ethelyn O. Greaves. *Bacteria in Relation to Soil Fertility*. D. Van Nostrand Company, 1925.

Haldane, Charlotte. *Man's World*. George H. Doran Company, 1927.

Housecraft. Vol. 45, 1972.

I Contain Multitudes. *A World Without Microbes: An Apocalyptic Thought Experiment*. PBS Digital Studios, 2018, https://www.youtube.com/watch?v=80tPR5HH9Zo.

"Is a Germless World Desirable?" *Dental Digest*, vol. 5, Oral Hygiene Division of the Petroleum Publishing Company, 1899, pp. 633–35.

Joshi, S. R. *Microbes: Redefined Personality*. APH Publishing, 2007.

Kijanizin, J. "Influence de l'air stérilisé sur l'assimilation, la désassimilation de l'azote et l'excrétion d'acide carbonique chez les animaux." *Archives de biologie*, vol. 13, 1895.

Kirk, Robert G. W. "'Life in a Germ-Free World': Isolating Life from the Laboratory Animal to the Bubble Boy." *Bulletin of the History of Medicine*, no. 86, 2012, pp. 237–75.

Kluyver, A. J. "Leeuwenhoek Lecture: The Changing Appraisal of the Microbe." *Proceedings of the Royal Society B*, vol. 141, 1952, pp. 147–61.

Lathrop, George Parsons. "In the Deep of Time." *The English Illustrated Magazine*, vol. XVI, 1896, pp. 679–93.

Lederberg, Joshua. "'Ome Sweet 'Omics-- A Genealogical Treasury of Words." *The Scientist*, Apr. 2001, http://www.the-scientist.com/?articles.view/articleNo/13313/title/-Ome-Sweet--Omics---A-Genealogical-Treasury-of-Words/.

Marius. "Vandals from the Moon." *Amazing Stories*, vol. 3, no. 4, July 1928, pp. 302–21.

Maughan, Tim. "Transmission." *Infectious Futures: Stories of the Post-Antibiotic Apocalypse*, edited by Brigitte Nerlich and Matthew Clarke, Nesta, 2015, pp. 21–26.

Metchnikoff, Élie. "Sur la flore du corps humain." *Manchester Memoirs*, vol. xlv, no. 5, May 1901, pp. 1–38.

Metchnikoff, Olga. "Note sur l'influence des microbes." *Annales de l'Institut Pasteur: Journal de microbiologie*, 1901, pp. 631–34.

Nencki, Marceli. "Bemerkungen zu einer bemerkung Pasteur's." *Archiv für experimentelle pathologie und pharmakologie*, vol. 20, no. 5–6, 1886, pp. 385–88.

Nerlich, Brigitte. "'The Post-Antibiotic Apocalypse' and the 'War on Superbugs': Catastrophe Discourse in Microbiology, Its Rhetorical Form and Political Function." *Public Understanding of Science*, vol. 18, no. 5, 2009, pp. 574–90.

Nuttall, George H. F., and H. Thierfelder. "Thierisches leben ohne bakterien im verdauungskanal." *Zeitschrift für physiologische chemie*, vol. 21, 96 1895, pp. 109–21.

O'Keefe, Pattric Ruth, et al. *Getting Acquainted.* The John C. Winston Company, 1954.

Ostherr, Kirsten. Cinematic Prophylaxis: Globalization and Contagion in the Discourse of World Health. Duke University Press, 2005.

Pasteur, Louis. "Note remise au Ministère de l'Instruction Publique et Des Cultes, sur sa demande, Avril 1862." *L'oeuvre de Pasteur*, edited by Henri Simmonet, 1862, p. T.VII, 3.

---. "Observations relatives à la note précédente de M. Duclaux; Par M. Pasteur." *Comptes rendus hebdomadaires des séances de l'Académie Des Sciences*, vol. 100, no. 1, 1885, p. 68.

---. "Pasteur on Fermentation." *Popular Science Monthly*, vol. 7, Oct. 1875.

Postgate, John. *Microbes and Man*. 2nd ed., Penguin Books, 1986.

Radin, Joanna. "The Speculative Present: How Michael Crichton Colonized the Future of Science and Technology." *Osiris*, vol. 34, no. 1, June 2019, pp. 297–315.

Rahn, Otto. *Microbes of Merit*. The Jacques Cattell Press, 1945.

Renard, Maurice. "A Man Among the Microbes." The Scientific Marvel Fiction of the French H. G. Wells: A Man Among the Microbes, translated by Brian Stableford.

Rossmoore, Harold W. *The Microbes, Our Unseen Friends*. Wayne State University Press, 1976.

Sachs, Jessica Snyder. Good Germs, Bad Germs: Health and Survival in a Bacterial World. Hill and Wang, 2007.

Schaechter, Moselio. "Talmudic Question #4." *Small Things Considered*, 19 Dec. 2006, http://schaechter.asmblog.org/schaechter/2006/12/talmudic_quesit.html.

Schottelius, Max. "Die bedeutung der darmbacteiren für die ernährung." *Archiv für hygiene und bakteriologie*, 1899, pp. 210–43.

Servitje, Lorenzo. "Gaming the Apocalypse in the Time of Antibiotic Resistance." *Osiris*, vol. 34, no. 1, June 2019, pp. 316–37.

Shiel, M. P. "The Future Day." *The Invisible Voices*, The Vanguard Press, 1936, pp. 264–83.

"The Relations of Microbes to Life." *Science*, vol. 5, no. 113, 1885, p. 268.

Verrill, A. Hyatt. "Beyond the Green Prism (Part II)." *Amazing Stories*, vol. 4, no. 11, Feb. 1930, pp. 1066–79.

Wald, Priscilla. Contagious: Cultures, Carriers, and the Outbreak Narrative. Duke University Press, 2008.

Wedberg, Stanley E. *Microbes and You*. The Macmillan Company, 1954.

Wells, H. G. *The Time Machine*. Henry Holt & Co, 1895.

---. The War of the Worlds. 1898.

Wesbrook, FF. "The Microscope in Medicine." *St. Paul Medical Journal*, vol. 4, no. 1902.

West, Wallace. "The Incubator Man." *Weird Tales*, vol. 12, no. 4, Oct. 1928, pp. 535–39.

Williamson, Jack. "The Evolution of the Martians." *The War of the Worlds: Fresh Perspectives on the H. G. Wells Classic*, BenBella Books, 2005, pp. 189–98.

Woese, Carl. *Microbial Life's Steadfast Champion*. Interview by Sandra Blakeslee, 15 Oct. 1996, http://www.nytimes.com/1996/10/15/science/microbial-life-s-steadfast-champion.html?pagewanted=all.

Wolstenholme, Gordon, editor. *Man and His Future*. Little, Brown, and Company, 1963.

Woodcock, John. "Disaster Thrillers: A Literary Mode of Technology Assessment." *Science, Technology, & Human Values*, vol. 4, no. 26, Winter 1979, pp. 37–45.

Zelinski, Helga. Microbes Mindcrobes: Human Entanglement with Microbes on a Physical, Mental, Emotional and Quantum Level. Xlibris Corporation, 2015.

Bursting the Bubble[40]

David Vetter spent his entire life waiting for the future to arrive. Diagnosed prenatally with Severe Combined Immunodeficiency (SCID), he was delivered by sterile Cesarean section in 1971 and transferred immediately to the plastic-film isolator that would earn him the nickname "Bubble Boy." The bubble was his refuge, a place of therapeutic safety against the microbes that would otherwise devastate his vulnerable body. And there he lived for twelve years, eating sterilized food and drinking sterilized water, reading sterilized books and doing schoolwork on sterilized paper, his entire world structured to preserve the integrity of the membrane surrounding him.

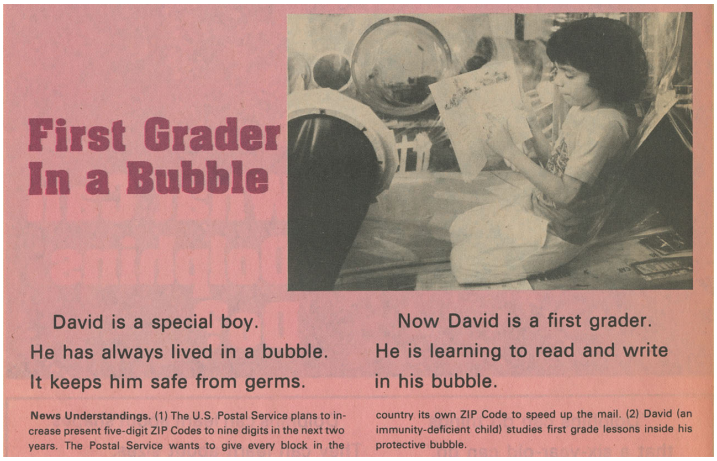

Figure 8. David Vetter featured in "First Grader in a Bubble," Buddy's Weekly Reader, January 1979. [Courtesy of Archives Center, National Museum of American History, Smithsonian Institution, Washington, DC.]

David—and the worldwide audience following his story—looked toward his eventual exit from that bubble, as medical researchers searched for a cure that would liberate him to a coexistence with the germs, and the people, of the world. In the public eye, David's confinement was often bemoaned, with news reports and magazines emphasizing the experiences and social contacts he lacked. Yet above all, his life was a medical miracle, "a triumphal tale of technological innovation

[40] A shorter version of this chapter was originally published as *"La Vie Impossible":* Germfree Life in the Microbiome Era" in *Practices of Speculation: Modeling, Embodiment, Figuration*, edited by Jeanne Cortiel et al., Transcript Verlag, 2020.

and medical mavericks" (Elman p.30). His bubble was, if regrettable, a place of safety. It was a refuge, a haven in which to wait (Figure 8).

As the first child to be kept alive long-term in a germfree space, he was also the biomedical future made manifest. David's case—his survival, normal development, and general good health—seemed to prophesy the salvation of other immunodeficient children, whose bodies would otherwise be fatally wracked in infancy by contact with microorganisms. But even more people stood to benefit, as well, as doctors and scientists began to wonder whether the technology extending his life might be used to treat ailments spanning the entire lifespan.

David's bubble had been made possible by eight decades of progressive refinement of the isolator technology first envisioned by Pasteur and implemented by Nuttall and Thierfelder. With the creation of David's bubble, the *human* germfree future appeared both achievable and imminent. When David was a year old, the keynote speaker at a prominent conference on germfree research, Wallace Herrell, predicted "that gnotobiotic research may have some clinical application in nearly every medical specialty and sub-specialty ranging from pediatrics to geriatrics" (11). He called for researchers "to immediately initiate extensive use of these germfree programs" (16). In the space age, that mission appeared as noble and as transformative as landing on the moon. Herrell asked, "if we can spend billions of dollars getting to the moon to find out among other things that it is germfree, why not spend a few million on the germfree programs?" (16–17). To many, David was an astronaut on Earth—a pioneer of life without germs.

Such boundless optimism in the saving power of medical technology was largely warranted in David's case. He lived to the age of twelve, fully a decade beyond the life expectancy of untreated SCID patients. The isolator technology was nearly flawless, and while he did acquire some microorganisms over time and was thus not strictly germfree, he evaded infection until the end of

his life. His death, in fact, resulted from efforts to bring him out of the bubble: a bone marrow transplant meant to confer a functional immune system harbored an undetected virus that cost him his life. David emerged from his bubble only in his last days, already grievously ill. It was the cure, then, and not the enclosure that killed him. Until the end, his bubble remained a protective space within which to survive and to thrive. Or so the story used to go. But that is not the David Vetter story of today.

In this time of the human microbiome, living without germs seems a bizarre, even contradictory prospect for a public increasingly familiar with the diverse and necessary roles of bacteria in human health. The changing assessment of microbes and disease has been particularly influenced by the vast body of popular science writing on the microbiome. This discourse, which I term "microbiome writing" in this chapter, spans news reports, journalistic interviews, books, videos and other media narrating microbiome research and its applications. Microbiome writing generally shares a common persuasive goal of convincing readers to leave behind outdated ideas of microbes as disease-causing invaders, to recognize their necessity to human life, and to live more intentionally with them. We simply cannot do without our microbes, these texts insist. We are barely human at all, according to Alanna Collen's book *10% Human: How Your Body's Microbes Hold the Key to Health and Happiness* (2015). We must attend to the tiny legions inside, according to Ed Yong's book *I Contain Multitudes: The Microbes within Us and a Grander View of Life* (2016). Or, as Rob Knight suggests in his TED talk, "How Our Microbes Make Us Who We Are" (2014), we must acknowledge our microbes, ourselves.

Even as microbiome writing celebrates the teeming abundance of microbial life, the thought of life without germs is never far from mind. The imagination of germfree enclosures has never ceased, but where fiction has historically installed humans of the future within their confines,

microbiome writing looks to embodied germfree animals as indicators of a contemporary human tragedy materially in progress. Particularly in the book-length texts that are the focus of this chapter, authors almost universally argue that microbiome research overturns the pervasive modern attitude of what might be termed *antibiosis*: a philosophy of "anti-life" in which microorganisms are viewed chiefly as antagonists to be eliminated at all costs.[41] Antibiosis encompasses antibiotic therapy as well as a host of contemporary practices, from hand sanitizers and Clorox wipes to hospital birth and processed foods, that systematically exclude the organisms with which humans coevolved. Microbiome books assert that the regime of antibiosis has resulted in a dramatic rise of noncommunicable diseases associated with the loss of microbial diversity. Almost in unison, authors claim that modern humans are on the brink of antimicrobial crisis. In his book *Missing Microbes: How the Overuse of Antibiotics Is Fueling Our Modern Plagues*, Martin Blaser even predicts an "antibiotic winter" of apocalyptic suffering should we fail to correct course (6).

Germfree life emblematizes that threat. David Vetter appears frequently in microbiome books, alongside gnotobiotic mice in their miniature bubbles. Authors recount visits to germfree animal facilities, cite research on gnotobiology, and delve into the history and technology of germfree isolators. Microbiome writers sometimes emphasize the research utility of germfree animals, namely, their role as negative controls in elucidating the influence of microorganisms on mammalian physiology, development, and neurobiology.[42] As research organisms, germfree animals are generally studied for their relevance to human biology; murine pathologies lead to inferences

[41] While I draw this term from (Landecker), where it is used specifically in the context of antibiotic drugs (20), it also accurately describes a more comprehensive attitude of "anti-life" in microbiome writing.

[42] Microbiome writing's engagement with gnotobiology occurs almost exclusively in the more capacious space of full-length books. Such texts began appearing with frequency around 2008, after the launch of the Human Microbiome Project in the U.S.

about human counterparts. In this sense, germfree mice serve as model organisms within biomedicine.[43]

In microbiome writing, however, germfree life is primarily deployed for its symbolic value. Gnotobiotic mice and David the Bubble Boy become figures for the microbially depleted modern body, products of the regime of antibiosis. This symbolism is made possible by a significant shift in their status. As represented in microbiome writing, the germfree state is no longer an achievement but rather a catastrophe, no longer lifegiving but rather intrinsically risky. If gnotobiotic organisms are model organisms in biomedicine, in microbiome writing they are more properly what anthropologists Heather Paxson and Stefan Helmreich have termed *model ecosystems*, functioning "in a prescriptive sense, as tokens of how organisms and human ecological relations with them *could*, *should*, or *might* be" (165). In this chapter, I show how microbiome writing employs germfree bodies as model ecosystems in reverse, as non-ecosystems held up prescriptively to illustrate how humans and microbes should not be, that is, separate. Germfree life signals grave costs to body, psyche, and society; it germinates a moral imperative to live with germs in the wider world.

The David Vetter story of today is a parable for the folly of attempting to live without germs, in which their absence, not their presence, is lethal. In this chapter, I show how microbiome writers accomplish the rewriting of his life and legacy into a register suited to the microbiome era. Conducting a close-reading analysis of ten popular science microbiome books, I examine how the history and status of germfree life—animal and human—are subtly reframed to align with the authors' critiques of antibiosis. Through a subtle web of historical disjunctions, recurring tropes, a touch of misquotation, and a dose of hyperbole, germfree life in the microbiome era becomes sick.

---

[43] They are model organisms in the sense that they produce findings generalizable beyond themselves and model whole-organism processes, such as human–microbe interactions (Ankeny and Leonelli). See (Davies) on the structuring role of narrative in shaping relations between animal biology and human disease, and (Rader) on the standardization of laboratory mice.

Transforming the germfree isolator from a historical invention to a modern one, from a protective space to an imminently dangerous one, microbiome writers reconceptualize germfree bodies as profoundly suffering, urgently in need of reintegration with the microbial world.

I argue that reappraisals of germfree life in microbiome writing are unified by a recurrent speculative maneuver in which the germfree body signifies the future made manifest, a small-scale perfection of antibiosis. Microbiome writers continually forge parallels between germfree organisms and human bodies overexposed to antibiotics, asking readers to identify the conditions of their own bodies replicated in the space of the gnotobiotic isolator. Germfree life comes not only to exemplify the present suffering of human bodies but also to foretell the devastating failures of body and society that are the terminus of antibiosis. As embodiments of a catastrophe already underway in the antibiotic-laden modern world, germfree mice and bubble boys are deployed as interventions in the present: they function as deterrents to the trajectory of antibiosis, revealing the crisis of life without germs as foretold by the bodies of germfree mice and David Vetter.

1. Living and Loving in a Bubble

The feverish excitement that accompanied David during his life was consistent with early fictional representations of germfree individuals. Although societies and worlds without germs had long been marked as intellectually flawed in fiction, as I show in Chapter 1, stories of single people bound long-term in isolators had been generally treated more positively—as innocent inhabitants of the future, even as they emphasized the costs of such a life. Gnotobiotic fiction foregrounds the emotional and social deprivations of individuals confined alone from birth onward, separated from their fellow humans by an isolator's invisible membrane. I term these stories "bubble kid fictions" because their protagonists are generally childlike, whether in age or in maturity. Bubble life grants

health at the expense of wellbeing, creating social and especially sexual deprivations that almost invariably prompt inhabitants to emerge into the wider world as a necessary step toward adulthood and individuation.

Early bubble kid fictions largely celebrated gnotobiology as a technological marvel affording longevity and intellectual achievement, though they are not without criticisms of the enterprise itself. Wallace West's short story "The Incubator Man," published in *Weird Tales* in October 1928, exhibits the familiar theme of wayward intellect. It features one Columbus Norton, a man who had been transferred into a gnotobiotic isolator at birth by a bacteriologist father intent on proving that living germfree would increase the lifespan. The younger Norton fulfils his father's prediction and is a robust 150 years old at the time of the story's events. He also masters the intellectual world, having grown up with the best books and instructors and plenty of time. Columbus eventually amasses the sum total of human learning, contributing to advances in medicine and beyond. As such, he is the embodiment of scientific knowledge, "the heart and soul of the scientific system" (538).

Yet the father's dream is also a delusion. Columbus describes a man obsessed: "He loved germs. He dreamed of germs. His whole life was filled with germ culture and the new and strange diseases he had discovered or had learned to check. In fact, he had almost ceased to be human" (535-6). The father's mad quest to overcome disease has threatened his very humanity; elsewhere, his son terms him "a soulless monster" (537). That inhumanity undermines the entire project.

While Columbus feels duty-bound to use his condition to help a world that was still "learning to control itself, and to live sanely and keep healthy and live long" (537), he also experiences his confinement as a "prison." Cut off from physical connection with other humans, Columbus falls victim to erotic desire. He writes, "one thing my father had not counted upon was the fact that I would become a man, with a man's dreams of love and fair women" (539). When a

temptress visits his incubator (Figure 9)—an actress appropriately named "Lilith"—he is rendered just as myopic as his father. Caught up in desire, he determines "to leave all this. Humanity must take care of itself. To be perfectly frank: to hell with humanity; I want out of this."

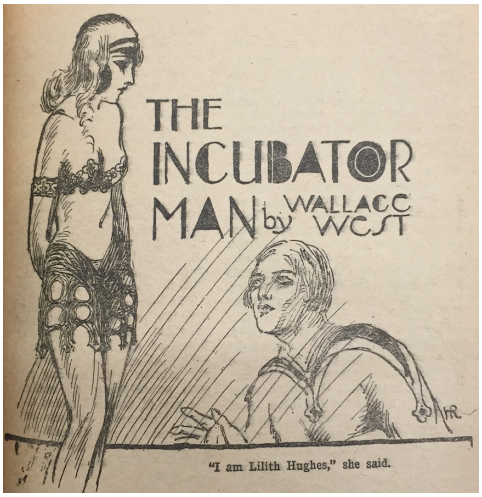

Figure 9. Columbus Norton meets Lilith in "The Incubator Man" (West).

Columbus breaks out of his enclosure, determined to follow Lilith to Los Angeles. He never completes the journey: he is taken ill with the measles and dies just two days after his emergence, his body having been left entirely unprepared for the microbial assaults of the wider world. West therefore identifies the germfree condition as one of unrealistic expectations and scientific irrationality. Gnotobiotic life is intolerable, threatening its inhabitant precisely because it divorces him from human contact.

Three decades later, Allen Kim Lang would revisit these themes in his sustained imagination of gnotobiotic humans. "World in a Bottle," published in *Galaxy Magazine* in October 1960, draws on the work of James Reyniers and others at the LOBUND Institute, University of Notre Dame, which at this time was trickling into the public imagination. It features John Bogardus, one of many "Lapins" who have been raised together in Central University's Big Tank (a gnotobiotic isolator) since their infancy. Like Columbus Norton, the Lapins are intellectually accomplished, leaders in the

fields of physics, medicine, and more. But they too suffer from their isolation. They grieve a fellow Lapin who left the bubble amidst a mental breakdown and died a gruesome death by pneumonia two days later and are haunted by the memory of a crack that once developed in the tank. Mostly though, they suffer heartbreak borne of their isolation. Bogardus explains that they experience sexual boredom amongst themselves, having been together since infancy. But attempts to find love in the wider world always fail. Bogardus himself breaks up with a real-world girlfriend, finding the imposition of his germfree "chastity-suit" too great a barrier to love. The Lapins suffer another loss when one of their number leaves in the name of love, dying two days after her marriage to a germy man.

Yet while the story lightheartedly satirizes the enterprise of germfree research (for instance, the Lapins are referred to as "canned-goods" or, for the women, "canned peaches"), it is also a rousing endorsement of human gnotobiology. In contrast with other bubble kid stories, "World in a Bottle" rejects the possibility of egress in the name of love. Even in the face of a looming mental health crisis amongst the entire Lapin population, they turn down the possibility of undergoing a safe acclimatization procedure. Bogardus insists on the nobility of their mission, casting the Lapins as "the gnotobiotic first-born, we Adams and Eves who were delivered into purity by aseptic Caesarian section." They therefore determine to recommit to science, dedicating themselves to a new research purpose: spaceflight.

Bogardus proposes to send the Lapins aboard a four-generation spaceship preparing to travel to Alpha Centauri.[44] He argues that only the Lapins can avoid the pitfalls that "'normal,' contaminated humans" would experience during a life in space:

[44] Bogardus was not alone in this idea: in *Popular Science* two years later, Robert Gannon interviewed a gnotobiology researcher who remarked "'All we have to do is keep a man in a germfree cabinet for some 25 years following birth, meanwhile teaching him to fly a spacecraft.' Dr. Phillips is only half joking" (83).

> We Lapins were born to crew the Zeta. Where else could you find a crew that's already spent twenty-odd years or so inside a box, living together in close quarters, being conditioned against claustrophobia? … Could you find a better crew than us twenty-eight, skilled in two dozen professions, young, sound of wind and limb, and willing as hell to take on the job? None of whom will ever have appendicitis, halitosis, toothache, barber's itch, or athlete's foot? Any one of whom can, in case of accident, first-aid his wounds with a spit-damp handkerchief, and heal wholesome? … We'll be the finest extra-solar crew that ever blasted free of the system!

The proposal is enthusiastically accepted. The story ends with Bogardus carrying a female Lapin onboard the Zeta, anticipating a matrimonial future of renewed sexual vigor. While the Lapins emerge from their Big Tank, it is ultimately into another germfree space—a vehicle, once more, of futurity.

"World in a Bottle" is unique among bubble kid stories for its unrestrained praise of gnotobiology, perhaps because the inclusion of a group of humans defuses the isolation of enclosure and thus makes thinkable the indefinite sacrifice of freedom to science. As tales of bubble life move forward in time, they adhere more fully to the model set by West—loneliness, sexual yearning, and escape—but without even the justification of scientific utility. Instead, their narratives undergo a deformation, increasingly foregrounding the sickness of those within.

David Vetter was one such bubble kid and his cultural appraisal fell largely along the same lines, casting him as a specimen of the future. He embodied both the glory of science and the suffering of isolation; his life was both saved and lost. During his life, David's story was told and retold, built upon in stories that, like West and Kim's, featured older bubble kids suffering from adolescent yearnings from within their enclosures. And even long after his death in 1984, bubble

kids survive in fiction, featuring in formulaic narratives of confinement, escape, and sexual awakening.[45]

Perhaps most influential of these fictions has been *The Boy in the Plastic Bubble,* the 1976 made-for-TV film directed by Randal Kleiser and starring John Travolta as the titular bubble boy, Tod Lubitch. The film was loosely based Vetter's life but hews more closely to the tales of gnotobiotic humans preceding him in fiction. Tod is lonely and isolated, accompanied in his bubble only by his pet germfree mouse, and like his predecessors must navigate the pitfalls of his sexual awakening as well as peer and parental pressures. But where Columbus Norton and the Lapins recognized their contributions to science, even as they chafed at them, Tod rejects any duty to science. His story is instead one of escape and fulfilment.

The film primarily narrates his growing romantic frustrations, with the bubble coming to signify (and to enforce) his emotional and sexual immaturity. Tod is socially awkward, rigorously over-protected by parents and doctors, and largely naïve about the outside world. His doctor describes him as willfully immature: "You have the best excuse of anybody to avoid growing up … sometimes you're like a grown man and sometimes you're like a newborn baby." On the other side is Gina, the worldly next-door neighbor with her boyfriends, cigarettes, and failing grades. She is also in possession of a body that Tod cannot help but notice especially when she appears scantily clad for a visit, much like Lilith in "The Incubator Man." As their relationship develops, Tod's perception of his sexual inexperience deepens, along with his realization that fulfilment is only possible by accepting the risks of both love and germs. If earlier bubble-kid stories featured inhabitants of preeminent intelligence and learning, for Tod and his fictional successors bubble life reveals to them how little they know.

[45] On the utopian futures perennially invoked by gnotobiology and bubble boys, see (Weinstein). On the particular cultural legacy of David Vetter, see (Elman).

Figure 10. Tod and Gina in The Boy in the Plastic Bubble (Kleiser).

The bubble is therefore the dividing line between naivete and knowledge, childhood and adulthood (Figure 10). As Tod's interest in Gina grows, remaining inside is no longer tolerable. His decision to cast off the warnings of parents and doctors and to flee with Gina is inevitable, an act of self-assertion and a mark of sexual maturity. That Tod's decision entails an awareness of risk underscores the film's departure from earlier narratives of self-sacrificing bubble kids. As Julie Passanante Elman observes, "the movie rescripted the bubble boy's exit from the protective bubble not as a heroic self-sacrifice for the advancement of medical knowledge but as the natural pursuit of (hetero)sexual liberation and self-actualization" (32). In this coming-of-age story, death is preferable to the loss of independence.

The Boy in the Plastic Bubble, alongside the avalanche of media coverage of Vetter's life, took germfree enclosures into the mainstream—into the realm of celebrity. These form an essential precedent for the microbiome era's resurrection of bubble-kid fictions, discussed at the end of this chapter, as a parable of germfree fantasy.

In 1978, the British punk band X-Ray Spex sang of "germfree adolescents." The album's title song equates sexual and bacterial sterility, depicting a young woman for whom "cleanliness is

her obsession / Cleans her teeth ten times a day / Scrub away, scrub away, scrub away." Germfreeness appears an attractive condition to her ("I'd like to get to know you / You're deep frozen like the ice."), yet also signifies a ritual untouchability: "You may get to touch her / If your gloves are sterilized / Rinse your mouth with Listerine / Blow disinfectant in her eyes." The album's cover art pictures the bandmates isolated into individual test tubes each pressing the walls outward, reinforcing the equation of germfree states with confinement and inaccessibility (Figure 11).

Figure 11. Cover art for Germfree Adolescents (X-ray Spex).

A year after Vetter's death, Bruce Sterling would reprise the theme in his novel *Schismatrix*. Germfree boundaries are a recurrent feature in this novel of human civilization dispersed into colonies scattered across the solar system. Travelers between worlds must be sterilized and then reseeded with local microorganisms so as not to disrupt the new planet's ecology; the same fate awaits planets whose ecosystems have gone off balance. As in "Germfree Adolescents," sexual and microbiological sterility coincide in groups of people who voluntarily live germfree, a status often associated with the Shapers, a culture of genetic engineers obsessed by the pursuit of bodily control. The encounter between protagonist Abelard Lindsay and the Mavrides family of Shapers brings this tension to the fore. The Mavrides live "clean" without germs and are terrified at the thought of contact with "contaminated" visitors; they are led by Nora, who is sexually inexperienced and

emotionally cold ("if you had my control," she tells Lindsay, "you wouldn't weep. Not even if they tore your heart out" [82]). Lindsay's arrival neutralizes both forms of sterility, leading to the grotesque destruction of the Mavrides' germfree gardens as well as skin and ear infections as microbes colonize their bodies—and at last, the sexual contact between Lindsay and Nora.

The literary and cultural history of bubble enclosure has embodied a critical stance toward germfree existence, even where the enclosure is lifegiving. These stories of germfree isolation and sexual politics pivot from David's story, reworking it into narrative arcs that culminate in sexual fulfilment; scientific obligation gives way to the weight of social isolation. Following David's death, his celebrity carried forward in an expanding cultural vocabulary that quickly outgrew the bounds of his actual life, solidifying around the consensus that life in a bubble, metaphorically speaking, is undesirable and even pathological. In the intervening decades, the rich catalogue of "life in a bubble" references spanning popular culture has almost always signified emotional or intellectual flaws.

Such references generally leave behind the theme of sexual deprivation, equating germfree conditions with intellectual derangement. The pattern is most readily apparent in treatments of germophobia, with asepsis (or the dream thereof) suggested to be the culmination of the quest for rational control. For instance, Don DeLillo's short story "The Black-and-White Ball" presents a version of FBI director J. Edgar Hoover revolted by political discord and garbage, "obsessed with hygiene" (80). In *Underworld,* DeLillo has "germ-free Edgar" (50) demanding the creation of "a clean room at the Bureau with unprecedented standards of hygiene … an environment completely free of contaminants, dust, bacteria, and so on, with big white lights shining down, where Edgar himself might like to spend time when he was feeling vulnerable to the forces around him" (560). Similarly, the TV show *Monk* features a central character who is a germophobic detective. In a 2006 episode,

Adrian Monk becomes panicked upon finding himself buried in garbage. His friend removes him to a germfree clean room at a computer factory, "the cleanest room in San Francisco," at which point Monk's mental acuity returns and he immediately solves the case (Levine). Germfree conditions soothe his fears while also facilitating, as is a theme in such fictions, a space for clear-thinking rationality.

Perhaps most prominently, however, the trope of "living in a bubble" has become associated with political failures of self-absorption. By 1986, Paul Simon was "think[ing] of the boy in the bubble." In his song, the Vetter reference heralds "the age of miracles and wonder" but also, inseparably, political violence. In allusions to apartheid South Africa and the assassination of JFK, Simon's song and accompanying music video link bubbles with an era of conflict and violence. The music video, while it does show a bubble-bound baby tumbling across the screen, more frequently encloses adults going about ordinary life in constricted visual spaces: screens, spaceship portals, and windows (Blashfield)(Figure 12). Bubblehood is thus a characteristic of adults in this cultural critique, signifying narrow perspective often oblivious to the crises of modern life.

Figure 12. Contained within their narrow bubble perspectives, the extras in Paul Simon's music video fail to notice the flaming missile soaring over their heads (Blashfield).

By 1992, the political valences of bubbles were unmistakable. In November of that year, William Safire observed in his "On Language" column in the *New York Times* that American presidents were increasingly being described as existing within a bubble, "the sometimes invisible but always palpable barrier" separating them from the public (Safire 1992). Safire describes numerous usages of "bubble" to describe presidential security as well as the ignorance produced by being carefully shielded from the wider world. For instance, he notes Ross Perot's repeated charge that George Bush was living in ignorance of the toll of the recession due to "'that insulated bubble they've created for the President.'" In a follow-up column two months later, Safire links the phrase decisively to *The Boy in the Plastic Bubble* and to Ronald Reagan's self-identification with Vetter in describing his isolation from the people beyond Pennsylvania Avenue (Safire 1993). The accompanying image details a bubble-bound President Bill Clinton, asleep in a floating bubble that hovers above the Washington, D.C. skyline, blissfully detached from the work of governing (Figure 13). This usage continues into the present day: "living in a bubble" indicates insularity, willful ignorance, or self-absorption, even as the phrase's originating sources have faded from view.

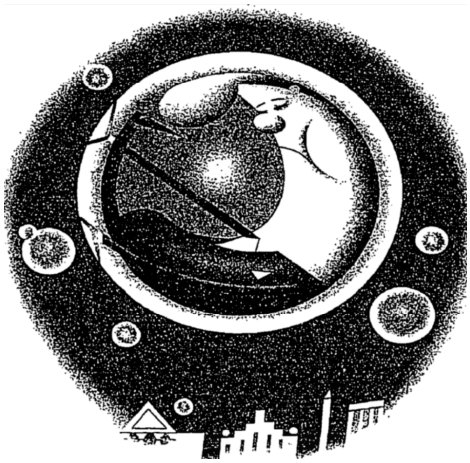

Figure 13. "The Man in the Big White Jail": Bill Clinton, safely ensconced in his bubble as illustrated in (Safire 1993).

Pasteur's 1885 hypothesis, it is now evident, gave rise to a diverse range of germfree imaginings as surely as it had to the material organisms now held in gnotobiotic isolators in research laboratories worldwide. From the outset, the germfree body—whether human or alien, young or old—has symbolized societal and intellectual deficiencies that call into question, as Pasteur did, the wisdom of severing ecological ties in a microbial world.

Contemporary microbiome writers harness these cultural precedents in their reassessments of gnotobiology, rewriting its history to suggest its emergence from the same central narrative of futurity, sacrifice, and short-sightedness. But in these retellings, the futurity of David Vetter and the pathology of "living in a bubble" is revised into a story for the material conditions of the present, powerfully symbolic of the regime of antibiosis. As I show below, microbiome writers as a group continually rewrite the stories of bubble life to fit within this symbolic framework, drawing on the robust cultural censure of isolator life to articulate the claim that the attempt to transcend germs is the product of deranged fantasy and reckless disregard for the consequences of aseptic life.

2. Germfree Dreaming

The long scientific history of germfree animals is seldom recognized in microbiome writing. Since the attainment of the first gnotobiotic chickens, guinea pigs, and tadpoles at the turn of the 20th century, gnotobiology has developed into a robust research discipline. Two major innovations enabled its expansion. First was the successful establishment of breeding colonies of germfree rats by two different research groups led by James A. Reyniers at LOBUND Institute, University of Notre Dame and Bengt Gustafsson and Güsta Glimstedt at the University of Lund in Sweden in 1946 and 1948, respectively (Reyniers et al.)(Gustafsson). While these colonies were begun from pups born by sterile C-section as in the early years of gnotobiology, thereafter they were able to

reproduce indefinitely within their isolators. Yet these stocks were confined to isolators that were still large, heavy, and immovable. The second key development was the development of lightweight, flexible plastic isolators, engineered by Reyniers's colleague Philip Trexler in 1957 (Figure 14). Cheap, stackable, shippable, and easily sterilized, Trexler's isolator allowed for the expansion of breeding colonies and the distribution of germfree animals to other research facilities. These innovations, alongside the refinement of feeding and supplementation regimes to compensate for the loss of microbes, allowed germfree organisms to survive long-term, thriving in their isolators in laboratories worldwide.[46]

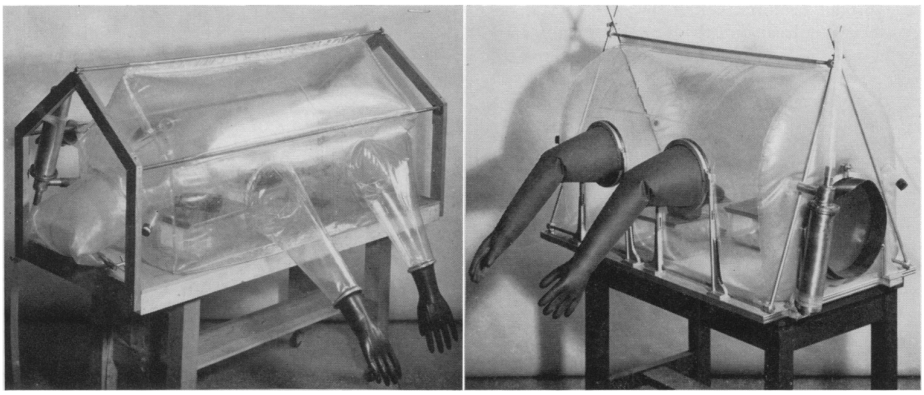

Figure 14. Philip Trexler's flexible film isolator as depicted in (Trexler and Reynolds).

Today, germfree animal colonies are generally begun at industrial laboratories, owned by companies such as Charles River Laboratories and Taconic Biosciences, and then transported to seed new colonies at any of the major university and industrial research centers housing gnotobiotic facilities (Figure 15). Gnotobiotic mice, in particular, have been crucial to the development of microbiome research. They afford the ability to assess the relationship between microorganisms and

[46] On the history of gnotobiology, see (Kirk 2012a) and (Kirk, "'Life in a Germ-Free World': Isolating Life from the Laboratory Animal to the Bubble Boy") and (Luckey). For a more comprehensive view of gnotobiology's applications, including in infectious disease research, see (Carter and Foster). The philosophers (O'Malley and Skillings) also discuss germfree animal research in relation to the history of microbiomics.

disease, both in organisms that are fully germfree (and which might exhibit particular physiological or immunological anomalies) and through specific manipulation of the microbiota in organisms that have a defined contingent of bacteria. Research in gnotobiotic animals was in fact crucial to the conception, justification, and execution of microbiome research.[47]

Figure 15. A technician at Charles River Laboratory tends colonies of germfree mice. Visible in these images are the flexible plastic film, attached gloves for handling mice, and multiple breeding colonies in separate cages. (Charles River)

The existence of breeding colonies of germfree animals, as documented in the scientific literature, thus demonstrates that life without microbes is quite possible. Contemporary microbiome writers, however, have recurrently resurrected Pasteur's hypothesis to affirm the sentiment that we simply cannot do without our microbes. "La vie impossible" thereby comes to signify not the life and death of a particular, isolator-bound chicken but rather the impossibility of human life in the absence of microorganisms—technical achievability aside. Pasteur's prediction becomes detached from his task of proposing the strategic exclusion of microbes, becoming remade into a claim, in the model-ecosystem mode, about the absent modern microbiome in an age of antibiosis.

The twenty-first-century rewriting of Pasteur is accomplished through a distortion of the historical development of germfree life that situates it in our more recent past. The misrepresentations I detail below are largely innocuous, likely arising from the simple fact that

[47] For a scientific perspective on microbiomics and gnotobiology see (Falk et al.). For a historical view of gnotobiology's influence on microbiome research, see (Schoeb and Rahija).

science writers are neither historians nor specialists in gnotobiology. Nevertheless, their renarrations of the historical record matter, helping to articulate an imminent crisis of post-microbial life looming large in microbiome writing.

Although they almost universally reference Pasteur's 1885 hypothesis, microbiome writers consistently obscure the long and largely successful early history of gnotobiology; the proposed experiment is generally suggested to have been left unexplored. In *Good Germs, Bad Germs: Health and Survival in a Bacterial World*, Jessica Snyder Sachs writes that "Pasteur's greatest protégé, the Nobel Prize-winning Elie Metchnikoff," believed that people would be better off without their bacteria, and he "openly scoffed at what he considered his mentor's naïveté" (29). Sachs frames Metchnikoff's rejection as the disdain of an insolent student, with material consequences: identifying Metchnikoff as leading the "winning" side in gnotobiological debates, she implies an institutional diminishing of the proposal, setting Pasteur in opposition to the (prize-winning, great) microbiological mainstream (30).

More broadly, microbiome writers steadily minimize the substantial successes of gnotobiology in the early nineteenth century. Sachs neglects to mention Metchnikoff's own deep investment in germfree animal research, casting him solely as critic of Pasteur. Similarly, she entirely overlooks his wife Olga's derivation of germfree tadpoles in 1901, crediting her instead with an "unsuccessful attempt to keep tadpoles alive under sterile conditions" (30).[48] Other microbiome writers repeat the pattern. In *The Psychobiotic Revolution: Mood, Food, and the New Science of the Gut-Brain Connection*, Scott C. Anderson and his coauthors note the eventual implementation of the germfree chicken isolation proposed by Pasteur. But rather than mentioning that germfree guinea pigs and other animals had already been isolated by 1899, they describe only the "decade of failure" before

[48] Five of Olga Metchnikoff's tadpoles lived, and remained sterile, beyond 63 days (Metchnikoff).

Schottelius was "finally able to breed germ-free chickens" (31–32). Likewise, in *The Wild Life of Our Bodies: Predators, Parasites, and Partners That Shape Who We Are Today*, Rob Dunn depicts early experiments in gnotobiology as relying on ineffective, low-tech methods of "scrubbing the germs off [...] a kind of Mr. Clean approach [...] Those attempts had failed" (68).

After decades of neglect or failed efforts, this narrative goes, germfree life finally emerged with force in the mid-twentieth century. While it is true that germfree research accelerated at this time, with specimens becoming more transportable and more commonly studied, microbiome writers generally suggest them to have been *invented* or even conceived of at this moment. The timeline is a point of general consensus among microbiome writers. Anderson et al. as well as Yong place its origins in the 1940s, while others are somewhat less precise. In *I, Superorganism: Learning to Love Your Inner Ecosystem*, Jon Turney says "50 years ago" (55). In *The Human Superorganism: How the Microbiome Is Revolutionizing the Pursuit of a Healthy Life*, Rodney Dietert says "forty to fifty" years ago (44). In *An Epidemic of Absence: A New Way of Understanding Allergies and Autoimmune Diseases*, Moises Velasquez-Manoff simply puts it in the "mid-twentieth century" (169).

In this vein, Dunn suggests Reyniers's isolator technology to have been the invention of a lone genius, first dreamed up in a heady era of technological innovation. He writes, "the iron lung had just been invented, as had the first robot. What if, Reyniers thought, he used the same sorts of technologies to construct a microbe-free world?" (68). Dunn's account assigns key insights from the first decade of gnotobiology, including Pasteur's recognition of the sterility of the chicken egg and the extension of this concept to the guinea pig by Nuttall and Thierfelder, to Reyniers himself.[49] He concludes, "if Reyniers could accomplish his goal, he might be the first person in history to produce an animal devoid of germs [...] Such an animal would be fascinating and modern" (68–69). In light

[49] The suggestion that the Cesarean delivery of germfree mice was an innovation of the mid-twentieth century is also made in Anderson et al. (33) and Velasquez-Manoff (169).

of the longer history of gnotobiology I have been discussing, of course, such an animal was neither modern nor invented by Reyniers.

If Dunn frames gnotobiology as a continuation of the technological advances of the mid-twentieth century, other authors link it more specifically to the antimicrobial advances of the same period. Anderson and his colleagues introduce Pasteur's hypothesis but only mention the actual existence of germfree animals following their section on penicillin, implying that it was only in the wake of antibiotics that germfree mice were "finally created" via C-section birth (33). Similarly, Velasquez-Manoff writes,

> Beginning in the mid-twentieth century, following a hundred years of almost miraculous progress in medicine—including the triumph of germ theory, the advent of antibiotics, and the polio vaccine—scientists finally looked into Pasteur's idea. They delivered mice by C-section, fed them sterile food, and raised them in germ- free bubbles [...] (169)

Velasquez-Manoff suggests Pasteur's vision to have lain dormant for a half century, emerging only after the solidification of a systemic program of microbial eradication, and from a cultural moment in which such progress was hailed as "miraculous" and a "triumph." Each of these books, then, suggests that Pasteur's vision of germfree animals could only be realized in the wonder-drug era.[50] Gnotobiology, disjointed from its historical origins, becomes symptomatic of a prevailing attitude of antibiosis.

Indeed, microbiome writers share a preoccupation with antibiotic drugs, which often function as symbolic distillations of a less-than-rational quest for control over germs and disease. Antibiotics metonymize an obsessive vision of microbial transcendence pursued at any cost.

---

[50] The historian Robert Bud has documented the robust cultural legacy of penicillin, namely, the drug's "associat[ion] with unprecedented power, science, and modern medicine" (74). Microbiome writers inherit these associations, with the gnotobiotic isolator recapitulating the familiar linkage between antibiotics and technological achievement.

Transported into the era of wonder drugs and vaccines, then, germfree animals become products of an ill-advised desire for life beyond germs.

For microbiome writers, germfree fantasy rather than technological rationality has guided the development of gnotobiology. Dunn's account in *The Wild Life of Our Bodies* features a Reyniers driven to the pursuit of germfree steel isolators by a fantasy of both personal and biological transcendence: he "dreamed of germfree rats and, with them, grandeur" (68). A lengthy discussion of Reyniers's work describes him as nearly crazed in his obsessive pursuit of the "dream" of germfree life, "interested, beyond reason" (67) in Pasteur's hypothesis and irrationally driven to disprove it. Dunn repeatedly emphasizes Reyniers's youth—he was nineteen—and calls him "a boy" (69, 70). Dunn also plays up Reyniers's unorthodox training as a machinist rather than as a biologist and his appointment to academic posts without the expected degrees. Dunn's Reyniers is an audacious dreamer, carried beyond reason in his imagination of germfree life. While other microbiome writers treat Reyniers with more circumspection, the situation of gnotobiology in a post-antibiotic world is widely echoed: the germfree animal in its germfree world is framed as the terminus, and culmination, of antibiosis.

Accusations such as Dunn's—that the pursuit of germfree life is rooted in unreasonable fantasy—recur throughout microbiome writing, particularly in discussions of the material elimination of microorganisms through antibiotics. In microbiome-era retellings of gnotobiological history, the discovery of penicillin is said to have launched the persistent imagination of a germfree human future. As Anderson and his collaborators put it,

> The world began to wonder: Could germs be completely eliminated? The idea of living in a sterilized world—a world free of disease—was tantalizing. People fantasized about a future in which children would be brought up as superkids, liberated by their germ-free

> environment. Without bacteria, they would never be sick and could live for hundreds of years. It was a vision of purity, a sparkling biological utopia. (32–33)

Wonder, fantasy, vision: penicillin gives rise irresistibly to the possibility of germfree utopia, to the wild dream of liberation from illness and death.

With germfree animals, microbiome writers suggest, the dream became real. Dunn attributes an irresistible allure to Reyniers's animals, suggesting that even scientists were led astray by the discovery that it was, after all, possible to live without microbes:

> Reyniers spoke often and with the weight of his institute and accomplishments. His voice came to dominate the field [...] Each new talk or study added punctuation until one could almost hear it, a drumming chorus of "Kill the germs!" "*Kill the germs!*" and we would be free of our past. Kill the germs and we would be healthier and happier, just like the guinea pigs in their giant metal worlds. (74)

The scientific response to Reyniers's guinea pigs, Dunn implies, has actually been a collective mania in which biologists' own antibiotic fantasies are recursively amplified by the materialization of germfree animals. Significantly, Dunn presents the scientific aspiration toward microbial transcendence as being motivated by an explicit desire to kill the germs, not merely to study life without them: gnotobiology is synonymous with microbicide.

The public, Dunn suggests, has been similarly affected by appearance of germfree animals. Noting that germfree animals generally outlive their conventional counterparts, he writes that Reyniers "had inspired the imagination of the masses, inspired them to believe that we all might live like his guinea pigs, germ-free and nearly forever" (73). Germfree guinea pigs were more than scientific model organisms, becoming also "a model of what was possible" and foretelling "the chambers of the future, where we were completely removed from the plagues of our past" (72–74).

But the imagined germfree future does not remain hypothetical: Dunn suggests that it has also driven efforts to manifest a germfree state in the present. For the public, such efforts take shape not as elaborate isolators but rather as more ordinary antimicrobial compulsions, attempts to "make our lives more like the lives in those guinea pig chambers" (74). Dunn declares antimicrobial actions to be attempts toward a literal germfree bubble, reinforced by the "barriers we attempt to erect with antibiotic wipes, antibiotic sprays, and the like" (76).

For Dunn, the familiar antimicrobial practices of daily human life are consistent with the same germfree dreaming that produced gnotobiology. This sentiment recurs across microbiome books, with authors continually equating modern life with a deeply rooted and irrational desire to eliminate, not just to manage, microorganisms. Dietert, in *The Human Superorganism*, laments our "modernized world of antibiotic-administered, formula-fed, cesarean-delivered babies growing up in urban environments, surrounded by hand sanitizers and antibacterial wipes" (6). Dietert suggests a spatial boundedness to this antibiotic lifestyle in which babies, not unlike germfree mice, are born and raised within strict barriers keeping germs at bay—as if living in a bubble.

The scientific literature characterizes the effects of depleted microbiome biodiversity as *dysbiosis:* a lost biodiversity reflected in an imbalance in the expected proportions, but not the total volume, of species comprising a body's microflora.[51] In popular science writing, however, dysbiosis is often reinvented as a state of microbiological barrenness. Microbes are not imbalanced, but rather gone entirely in an "epidemic of absence" (Velasquez-Manoff 2012) and a crisis of "missing microbes" (Blaser 2014). The human body perceives the loss: Blaser describes "a dance without a partner" (122), Dunn a "longing" or "an ache for the context you miss," like the "pain of a missing limb" (23, xii, xiii). These tropes are supplemented by microbiome writing's proliferation of

[51] For a philosophical critique of the explanatory potential of dysbiosis: O'Malley and Skillings (2018).

environmental destruction metaphors, such that the antibiotic-laden modern body is said to suffer like a landscape that is scorched, deforested, desolate without its extinct species, and polluted by nuclear fallout.[52] Contained within antibiotic barriers rigorously maintained, the human body becomes figuratively germfree.

Microbiome writers do not hold that our bodies are literally germfree, but rather that the germfree imagination continues unabated in a continual striving toward germfree utopia. It is in this trajectory that they seek to intervene. The solution to germfree fantasy, according to these authors, is scientific rationality. They suggest that microbiome science, with its sobering attention to the consequences of microbial depletion, can puncture the inflated dream of life beyond germs. Microbiomic rationality exposes the germfree dream to be a germfree nightmare; it defines the microbeless body as disastrous rather than transcendent.

In advocating for a saner approach to germs, microbiome writers take on the rhetorical mantle of historical antibiotic reformers: mid-twentieth-century infectious disease researchers who sought to curb the overzealous use of antibiotics. According to Scott H. Podolsky, reformers defined the overuse of antibiotics as driven by a deep-seated irrationality, and they advocated for "therapeutic rationality" in response (2). For microbiome writers, too, accusations of irrationality sharpen arguments for a more sparing use of antibiotics as well as a more deliberate approach to living with microorganisms.[53] Time and again, the yearning for life without microbes is countered by an emphasis on the risks of such a life. As we will see, the "impossible life" of the germfree organism comes to mean something worse than death: a life of unbearable suffering.

---

[52] Blaser employs these metaphors relentlessly, but they abound across microbiome writing. They are inherited, in part, from antibiotic reformers' tendency toward natural destruction metaphors (Podolsky) and contemporary catastrophe discourse in microbiology (Nerlich).

[53] On hysteria surrounding microbes and the "gospel of germs," see (Tomes); on American culture's particular obsession with cleanliness, see (Hoy).

3. The Suffering of a Lost Microbiome

Living without germs leaves a mark. From the outset of gnotobiology, scientists have identified multiple physiological and immunological anomalies of gnotobiosis: altered anatomical features, digestive and metabolic anomalies, heightened nutrient requirements, and more.[54] Yet these anomalies are familiar, well characterized, and manageable. When successfully accommodated with the appropriate supplements and care, germfree animals thrive. In itself, germfreeness is not an obstacle to long-term survival. Gnotobiotic animals even tend to outlive their conventional counterparts.

The gnotobiotic isolator might reasonably be considered a triumph of engineering and, given its success in medicine, a lifesaving innovation. But microbiome writers define the technology almost exclusively as transgressive—as Dunn writes, "monstrous" (73). Monstrosity, not achievement, characterizes the mission to separate an organism from its microbes. Other authors also describe germfree isolators as violations of the natural order, emphasizing their strangeness, awkwardness, or sheer technological immensity: Ed Yong calls them "some of the strangest environments in the world" (112); Turney, "an expensive and awkward business" (55). The monstrous space of the isolator extends to the bodies enclosed within, as microbiome writers consistently transform the familiar physiological anomalies of the germfree mouse into indicators of suffering. Difference becomes abnormality; isolation becomes pathology. Germfree mice are remade as victims, irreparably harmed and decisively artificial.

The artifice of germfree life, for instance, is highlighted in microbiome writers' frequent assertion that all germfree mice are Cesarean-delivered before being transferred to their isolators.[55]

---

[54] See (Carter and Foster) and, for a historical perspective, Gordon and Pesti (1971).
[55] E.g. (Turney); (Rosebury); and (Velasquez-Manoff).

While this procedure has remained in use since the nineteenth century, it has largely been eliminated, except in the establishment of new colonies, due to the development of breeding colonies in which animals give birth without intervention. Rampant C-section birth is a convenient suggestion, however, for writers wishing to establish these animals as thoroughly artificial—reproductively inviable—from birth to death. With assisted obstetrics a condition of their very existence, they embody a horrifying vision of technological intrusion: babies wrested from mothers, skin replaced with iron.

The pattern repeats in discussions of the distinctive physiologies of germfree mice. Microbiome writers seldom acknowledge that scientists modify the care of germfree animals to ensure their long-term survival, instead defining difference itself as pathological. Influential microbiologist and proto-microbiome writer Theodor Rosebury set this tone in his 1969 book, *Life on Man*, writing that germfree animals "turn out to be puny and deformed [...] with deficiencies and weaknesses yet to be counted" (149).[56] Contemporary writers follow Rosebury's lead, almost always portraying these animals as both deformed and deficient. Sachs recites a litany of defects: "unusually thin" intestinal tracts, and bodies "unusually vulnerable" to toxins and "unusually susceptible to deadly infections" (45). Sachs does not mention that these differences are managed by researchers; rather, the unusual physiology of the germfree mouse becomes intrinsically problematic.

Germfree mouse bodies are sometimes more overtly characterized as grotesque. Yong notes the "weird biology of germ-free animals" (54), while Velasquez-Manoff depicts them as having a "really weird" physiology that is "off," "abnormal," "malformed," "strange," "shrunken," and "arrested" (169-170). For Collen, they are revolting: an animal researcher she interviews recalls "that

[56] I include Rosebury's work in this chapter because it has been particularly influential for microbiome scientists as well as popular science writers, and because it prefigures many of the themes and narratives of contemporary microbiome books.

the first time she dissected a germ-free mouse, she was horrified by the size of the caecum, which took up most of the space in the abdomen" (128). The researcher's horror is recreated for the reader thanks to the inclusion of colored images of flayed mouse guts, in which the conventional as well as the germfree cecum might well be repulsive to the average reader. For these writers, the normal physiological differences of the germfree body are equated with suffering.

Significantly, in these accounts the research utility of germfree animals is rarely discussed; their crucial contributions to the study of human-microbial ecology go unnoticed. Instead, they are deployed primarily for their symbolic value. Transformed into bodily victims of a regime that values germfreeness above function and accepts countless deformities as the cost of its achievement, germfree mice are meant to be startlingly familiar. As depicted by microbiome writers, the grotesque germfree body is both alien and deeply resonant with the human bodies also suffering the consequences of antibiosis. Mice and humans are common victims of the dream of a germfree world.

Microbiome writers generally suggest that the microbially-depleted human body suffers profoundly in its "dance without a partner." Blaser even describes the lost biodiversity of the human microbiome as "exacting a terrible price":

> We are suffering from a mysterious array of what I call "modern plagues": obesity, childhood diabetes, asthma, hay fever, food allergies, esophageal reflux and cancer, celiac disease, Crohn's disease, ulcerative colitis, autism, eczema [...] Unlike most lethal plagues of the past that struck relatively fast and hard, these are chronic conditions that diminish and degrade their victims' quality of life for decades. (6, 2)

In Blaser's assessment, these modern plagues are unleashing an unprecedented misery that is subtler than infectious diseases—the "lethal plagues of the past"— but no less profound. He suggests an

urgent need to become attuned to these newer, more nuanced illnesses produced by the damaged microbiome.

We are meant to recognize ourselves within the space of the germfree isolator, identifying the bodily afflictions wrought by our own antimicrobial dreams. Contemporary human bodies mirror the "monstrous" germfree mice in microbiome writing, even if they do not (yet) appear so grotesque. In this sense, germfree animals might be understood as serving a *diagnostic* function, presenting afflictions that allow humans to identify their own dysbiotic suffering even in a not-quite-germfree world. The gnotobiotic isolator and the modern human world thereby become parallel spaces, limned spatially or rhetorically by a sterile boundary within which life suffers.

But the key innovation of microbiome writing's reappraisal of germfree life is that it is more than merely diagnostic of present human illness, also serving a crucial *deterrent* function; the virtual witnessing of germfree catastrophe is mobilized to intervene in the future. Microbiome writers generally suggest that the crisis of noncommunicable diseases, already dangerously out of control, threatens to worsen as the germfree fantasy draws ever closer to completion. Germfree mice and David Vetter, as early manifestations of that dream, suggest humanity's trajectory. Revealing the germfree dream to be a biological catastrophe, they are deployed to startle the reader into a more rational apprehension of microbial life and to forestall the devastations of antibiosis.

There is abundant precedent for this speculative neutralization of the germfree dream, in both fiction and scientific writing, as evidenced in Chapter 1: germfree states are the product of hubris and overreach. And so the idea that the aspiration toward life beyond germs accelerates a catastrophe of suffering is familiar, a mode of countering germophobia by harnessing the apocalyptic imagination. In microbiome writing, gnotobiology is made to teach the same lesson, only in microcosm.

In their engagements with germfree life, microbiome writers largely reprise the lessons of Crichton's Kalocin, Rahn's antimicrobial comet, and countless other devices historically recruited to illustrate graphically the toll of the germfree aspiration. Yet where these precursors have always announced themselves as thought experiments or as science fiction, microbiome writers extract the same insight from real, embodied organisms. One need no longer turn to the imagination, it would seem; looking into the gnotobiotic isolator brings the germfree nightmare to life before our very eyes. As perfections of an abiotic state dreamed of but not hitherto attained in the human world, germfree animals materialize antibiosis and its costs.

Rosebury first brought this speculative maneuver to microbiome writing in his discussion of gnotobiology. He writes that the numerous deficiencies of germfree animals demand we "abolish at once any notion we might have had that the animal would be generally better off without his germs [...] The germ-free animal is, by and large, a miserable creature" (49). Rosebury here comments on more than simply the status of germfree animals: his detailing of their miseries serves to rebut the notion that life without germs might be desirable— for humans. Animal misery forebodes human misery. He continues, "Knowing things like this, would you willingly separate your infant from his microbes if you could? Or ought you to be glad you can't?" (54). The paired questions affirm the stubborn persistence of gnotobiotic fantasy, despite the recognition that its achievement would be devastating. For Rosebury, that aspiration might only be dispelled by a speculative intervention: by asking the reader to imagine their own infant as germfree and therefore subject to the atrocities wreaked upon gnotobiotic animals.

Contemporary microbiome writers also turn to germfree animals as indicators of human suffering, though they generally assert a stronger potency for the deterrent possibilities of germfree imagination. Dietert is perhaps the most explicit in identifying the speculative mode animating

microbiome writers' engagements with germfree life. He explicates at some length a 1971 gnotobiology review article summarizing the physiological anomalies of germfree animals.[57] Significantly, Dietert interprets the article as a catalogue of present and future *human* horrors, despite the fact that it makes no claims about human applications. He argues that it "foretells exactly what happens when we are a single mammalian species. Without those microbes, we face a life of biological deficiencies, illnesses, and death" (44). From the bodies of gnotobiotic animals, he extrapolates to a dire human future of required nutritional supplements, swelling, immune susceptibility, and imminent death. It is germfree animals that lead him to conclude that "there are consequences to degrading or damaging the human microbiome garden," which is absolutely required in order "to have a healthy and prolonged life" (45).

For Dietert, germfree animals are more than model organisms; they also foretell our impending germfree future. It is a vision from which the reader is meant to recoil, to be surprised into a new appreciation of microbial life. Recognizing the kinship of this maneuver with the sorts of science fictional devices I mentioned above, Dietert explains his symbolic use of germfree organisms through the lens of speculative fiction:

> A wealth of studies in rodents and other animals shows us what happens when the microbiome is degraded, damaged, or even lost. The storyline strikes me as a little similar to the classic Frank Capra movie *It's a Wonderful Life*. We have the in- formation to look ahead and see what the future brings for living with a damaged microbiome. It is not pretty. It is not something we would want for ourselves or our children. (44)

Germfree animals, then, are our future. In them we are meant to glimpse the culmination of antibiotic fantasy, and to find it so appalling that we are provoked to reject such fantasy. With this

[57] The review, which goes uncited, is likely Gordon and Pesti (1971).

digression, Dietert asks his readers to take on the role of George Bailey, the protagonist of *It's a Wonderful Life* (1946) who wishes he'd never been born. The film narrates Bailey's glimpsing of a world without him—that is, a world in which impulsive dreams of absence are actualized. Merely a glimpse is enough to affirm for Bailey the necessity of reintegrating with his social and familial context. The same is meant to be true for readers of Dietert's book: merely a glimpse of the post-microbial future, as embodied in germfree mice, should affirm the necessity of reintegrating with one's micro-ecological context. An apocalyptic vision of the future thus comes to prevent that vision coming true.

4. The Germs That Bind

Nowhere is the imminent futurity of gnotobiosis more evident than in the case of David Vetter, whose bubble-bound form is continually recruited by microbiome writers to define the costs of life without germs. Where gnotobiotic animals generally illustrate physiological effects, however, David's humanity enables an argument for the social consequences of germfree life. Paxson and Helmreich write that as model ecosystems, microbial communities are "made to signify larger biological worlds and socialities, wider perils and promises, in worlds imagined yet to come" (171). David's story is only nominally about a celebrity of the past. As told by microbiome writers, it also entails a model-ecosystem claim in which David signifies the promises and, especially, the perils of imagined worlds without germs. As with the germfree mice discussed above, his story is retold as a deterrent: the recitation of his struggles is intended to guide readers to step out of their own bubbles and into a life interconnected with human and microbial bodies.

In microbiome writing, David's enclosure in the bubble is generally suggested to have been motivated by irrational germophobia more than any therapeutic agenda. He becomes the product of

the persistent dream of life beyond germs first realized in gnotobiology. In *The Psychobiotic Revolution*, Anderson and his coauthors claim that penicillin launched dreams of "superkids" raised in "a sparkling biological utopia" (32–33)—and David seemed to materialize those dreams. They write that "in 1971 the ultimate germ-free animal was created: a human."[58] As *ultimate* germfree animal, David here becomes the culmination—the dream come true—of both antibiotics and gnotobiology. It is a claim echoed by Dunn in *The Wild Life of Our Bodies*, writing that David's life and eventual death resulted from the belief that "we might achieve some germ-free utopia for ourselves" (76).[59]

Framed as the achievement of germfree utopia, David is transformed into gnotobiotic specimen. His SCID diagnosis recedes; his dramatically improved lifespan is forgotten. Instead, he is made to exemplify the catastrophically missing contemporary microbiome. In reality, he was not germfree, possessing a limited microflora due to leaks and contaminations (Williamson 1977). Microbiome writers consistently disregard that fact. Anderson and his colleagues insist that this "ultimate germ-free animal" was "freed from germs" (34). That point is echoed by Dietert, who asserts that he had "no immune system and no microbiome to co-mature with him and to enable him to function biologically in the environment of the world" (73–74)—a phrasing that strongly implies that it was gnotobiosis, rather than SCID, from which David suffered. As we will see, in this regard David aligns with the bubble kids being remade in contemporary fiction, similarly recast as victim of antibiotic hoax.

In the context of microbiome writing's preoccupation with gnotobiology, readers are encouraged to consider David's putative germfreeness with the deformity and physiological suffering so consistently attributed to germfree animals. No longer an engineering triumph, no

[58] Kirk details the early history of gnotobiological therapeutics, writing that these precedents "helped determine David's role as an object of scientific interest, comparable, if not directly akin, to the laboratory animal" (2012a p.269).
[59] Weinstein describes gnotobiology's perennial invitation of utopian dreaming (17–27).

longer a safe space, the bubble comes to signify a violation of the natural order. Crucially, though, David's own story complicates this narrative: microbiome writers must confront the inconvenient fact of his physiological normalcy. Physically healthy, typically developing, charismatic and curious even under the circumstances of his confinement, David fails to exhibit the deficiencies so insistently associated with germfree life in microbiome writing.

In *10% Human*, Collen reconciles this contradiction by allowing David to have been less-than-fully germfree. She explains his microflora as the result of medical failure: "Despite their best efforts to keep David germ-free, from birth onward his gut had been colonised by more and more species of bacteria" (127). Collen suggests those bacteria to have been his salvation; had the bubble been executed as intended, the results would have been disastrous. The hypothetical here becomes an occasion to invoke the speculative-deterrent mode of germfree life once more:

> Had David been truly germ-free, the coroner at his autopsy might have discovered that David's digestive system was drastically out of proportion. The first tennis-ball-like section of the large intestine—the caecum—to which the appendix is attached, might have been more like a football than a tennis ball. The folded surface of the small intestine would probably have had a much smaller surface area than normal, and fewer blood vessels supplying it. As it was, David's digestive system was as normal as any other child's. (128)

Might have been, but was not: Collen composes an alternative history in which David's body, enclosed in a perfected germfree isolator, bears identity with the anomalies of germfree mice. Her enumeration of digestive aberrancies that might have been is reinforced by her description and graphic illustration of the 'horrifyingly' enlarged mouse cecum, as noted above. Gnotobiotic disaster has been forestalled by the lifesaving presence of a few accidental microbes. It is a maneuver meant to correct the course of germfree dreaming, not only for David but also for the reader.

Other microbiome writers resolve the apparent contradiction of healthy germfreeness by rewriting his biography into a story of unrelenting anguish that is not physical but rather social, emotional, and societal. In this they align with the robust cultural censure of isolator life and bubble boys that has emerged since David's death: the movies, songs, and literature that have portrayed bubble boys as both miraculous and victimized, heroically surviving in the face of profound, if intangible costs.[60] They also converge with the more general condemnation of "living in a bubble," that is, inhabiting a perspective that is sheltered or shortsighted, divorced from intellectual context. Microbiome writers harness these diverse meanings, transmuting them into a condemnation of antibiosis. The bubble is not the problem; the missing microbiome is the problem. Taking David to be the embodiment of the epidemic of absence, these authors rewrite his legacy, together crafting a consistent narrative of profound social suffering.

In these accounts, David is simply "bubble boy," sometimes anonymous beyond this familiar nickname, and always defined by deprivation. Collen narrates a life of total social isolation:

> David was born in 1971 by Caesarean section into a sterile plastic bubble. He was handled through plastic gloves and fed sterilised infant formula. He never knew the scent of his mother's skin, or the touch of his father's hand. He never played with another child without plastic sheeting preventing the sharing of toys and laughter. (127)

Collen narrates his life almost exclusively in the negative, through a list of things never known and sensations never felt. Gone is the celebratory tone with which the media documented David's story while he lived; here and elsewhere, microbiome writers emphasize only lack.

And from that lack follows an encompassing desolation. In *The Psychobiotic Revolution*, Anderson and his colleagues emphasize the boy's psychological distress:

[60] Elman (2014) has extensively charted the cultural memory of Vetter's life.

> David didn't take long to realize that he was doomed to be cut off from the world, and he started questioning his life. He was depressed, but whether that was from being germ free or just because he lived in a plastic bubble with no physical human contact is debatable. (34)

Again, David is defined exclusively by isolation and lack. His depression is suggested to be due either to his germfree state or to his isolation; it is therefore remediable only by integration with the human and germy world, an integration incompatible with his own survival.

In Dunn's *The Wild Life of Our Bodies*, social isolation appears to be the indirect cause of death. Omitting the contributions of David's very involved parents and sister, as well as his participation in birthday parties, classrooms, and other hallmarks of normal life (Figure 16), Dunn writes that "inside his chamber, he was raised by doctors until the age of twelve" (76). Like some Mowgli raised by wolves, this David exists entirely beyond the human realm, a separation that he attempts to transcend with grave consequences. Dunn continues, "at twelve, he wanted out. At twelve, something needed to change and so he was given a bone marrow transplant in an attempt to restore his immune system" (76).[61] That this transplant ultimately ended his life consolidates David's status as a sufferer of the fatal pathology of isolation. To live with people is to live with germs; their lack is unsustainable on any level.

[61] Dunn's implication of adolescent rebellion is consistent with representations of David's life as a coming-of-age tale, especially in film adaptations (Elman 2014).

Figure 16. David Vetter with his parents, sister, and family dog. Photograph archived in the David Vetter Collection (1971–1986): Box 9 (David Vetter and Family, 1976–1983). Courtesy of Archives Center, National Museum of American History, Smithsonian Institution.

In retelling David's story, these authors highlight the denial of desires universal to human experience—for a parent's touch, for friendly interaction, for shared laughter and a bit of teenage rebellion—and so forge an argument for the *social* suffering of the germfree state. Microbiome writers generally describe the toll of dysbiosis for ordinary people in similar terms, suggesting that the resulting illnesses resulting from a too-clean environment force sufferers into conditions of social withdrawal. In *Good Germs, Bad Germs*, Sachs details the plights of two young boys whose severe food allergies force them to withdraw from friends, classmates, and even family (7, 73). In *An Epidemic of Absence*, Velasquez-Manoff describes "asthmatic teenagers wondering if they'll be able to join friends in a game of baseball" (6). David's case shows this social cost at its most extreme. Once more, germfree life is invoked as a deterrent to the dream of life beyond germs.

In microbiome writing, however, David symbolizes more than merely individual isolation. His germfreeness also forebodes a societal breakdown felt well beyond his bubble. In *The Human Superorganism,* Dietert pivots from David to expansive claims about the consequences of microbial

depletion at the societal level, depicting a dramatic rise in "microbially incomplete" babies—an entire "incomplete generation" (73). Dietert takes David's bubble to be an outward indicator of his own "microbial incompleteness," a state that kept him "removed from the world's normal environment and segregated into a completely artificial environment" (74). Dietert, in other words, identifies David's segregation as the fate awaiting the incomplete generation. He observes that the skyrocketing rate of dysbiotic illness means that "increasing numbers of us may have severely restricted environments in which we can safely function" and "restrict[ed] access to the full environment normally enjoyed by others" (74). The result is a widespread "social fracturing," detectable in a breakdown of social cohesion (76). With food allergies, for instance, familiar social rituals come unglued:

> Individuals may [...] have to withdraw from what used to be routine social gatherings and interactions with friends, family, and business colleagues [...] Holiday dinner celebrations, wedding receptions, community dinners, summer picnics, conference meals, and even single-family meals are increasingly affected. (76)

Dietert calls these deprivations a "new cost in human capital, our capacity to congregate around a meal, and a type of freedom humans used to have" (77).

David thus portends the looming societal disasters produced by the pursuit of life beyond germs. Echoing his description of Vetter as "segregated" into his bubble, Dietert suggests that the social withdrawal necessitated by dysbiotic illness threatens to solidify into full-fledged institutionalized injustice. He predicts a recapitulation of the "physical segregation of people in the course of human his- tory" due to factors such as "race, religion, lifestyle [...] politics, and wealth" (77). Invoking leper colonies and the Indian caste system, Dietert here articulates the most sweeping

extrapolation possible from David's isolator, looking to a future fractured by "an ever-increasing divide among humans" (78).

In microbiome writing, then, David represents both the individual and the social costs of antibiosis. Further, his life comes to represent a germfree catastrophe threatening all of society, in which people are held apart from one another as from the germs that bind—from the germs that constitute the very fabric of functional society.

David's story comes to represent how much we stand to lose should we fail to stop dreaming of a world without microbes. He thus becomes, for Anderson et al., the "ultimate germ-free animal" in a second sense: the last and final germ-free animal, such that there will be no more bubble boys. The authors write of his death:

> The public was taken aback by this human experiment that had gone so wrong, and at a stroke, it seemed, we awoke from the dream of a germ-free world. David, freed from germs, was not a superkid. The microbes, it seemed, had won a reprieve. (34)

A sudden, unified awakening: this is the impact of witnessing David's life and death, in a phrasing that encapsulates the use of germfree life in microbiome writing more broadly. David and his various miseries, like the deformities attributed to germfree mice, are suggested to carry with them the power to rouse an entire society (or at least, a diligent reader) from a decades-long dream of life beyond germs. Fantasy is countered with a speculative glimpse of our own future and, at a stroke, we awake.

5. The Hoaxing of Modern Bubble Kids

Our wider culture has continued to reckon with David's life and legacy in ways that are less overtly tied to scientific research. In particular, contemporary fiction has seen a resurgence of bubble

kid narratives. But where stories like West's and Kim's historically presented germfreeness as an audacious, misguided quest, contemporary fictions present bubble life as an exercise in smaller, more remediable germophobias. The germfree state becomes fixable, its dilemmas reconciled in the transition into a germy world: an updated narrative suited to a new, microbially conscious generation.

These stories generally position themselves as successors to the bubble kids of earlier generations. Madeline Whittier, the housebound heroine of Nicola Yoon's 2015 novel *Everything, Everything*, describes her illness as "bubble boy disease" (3) in an echo of Vetter's public nickname. Stewart Foster's 2016 novel *The Bubble Boy* makes the same nod, not only in the title but in a sustained retelling of the familiar narrative: like Vetter, the central character, Joe, is confined to a hospital, covered extensively in the media, and wears a spacesuit to get around.

Contemporary bubble-kid fiction also adopts essentially the same narrative as earlier versions, with striking uniformity. Like West's Incubator Man and Lang's Lapins, modern bubble kids tend to be smart—they have lots of time for books and few distractions! Madeline, for instance, keeps busy with book reviews and art and is sharp-witted and funny. But it is generally a hypothetical form of knowledge, marked by its distance from the real world. Like Travolta's Tod, bubble kids are generally clad in white, symbolic of their persistence in a state of innocence.

From their sheltered bubbles, they scrutinize the outer world while yearning for an escape that they can only imagine. They are generally represented as gazing outward at the world beyond. For example, in Jenni Hill's short story "They Want to Live Too," a young girl, Yuki, quarantined in a post-antibiotic world watches wistfully as neighborhood kids ride by on their bikes (Figure 17).

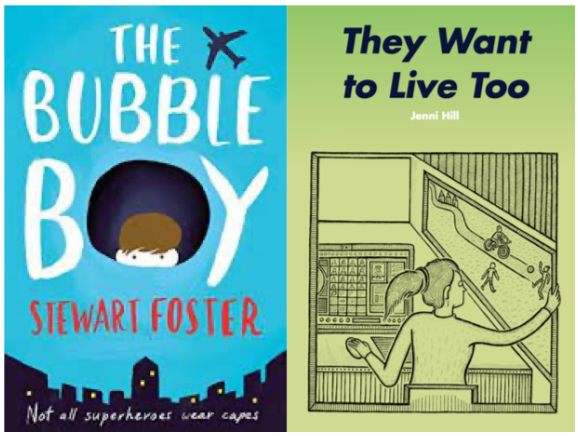

Figure 17. Foster's Joe and Hill's Yuki: bubble kids yearning for the world beyond.

These narratives sometimes focalize that outward yearning explicitly as fantasy. In *Everything, Everything*'s (Meghie 2017), Madeline romantically runs across a sunlit field into Olly's embrace. A similar sequence occurs in the 2019 horror film *Eli,* featuring a young boy confined to a clean house in order to protect him from his immune disease (Foy). Here too, is the fantasy of germs and freedom: the film opens on a smiling Eli racing across a field toward a distant table set for a party. In both films, the disorienting taste of freedom is cut short. Madeline and Eli each stagger to the ground, falling graphically ill just before reaching their destination. They remember their illness at the same time as the viewer becomes cognizant of it, as the longing for freedom confronts physical reality and the reminder that touch, play, and happiness are unattainable.

Or are they? Like their precursors in fiction, modern bubble kids inevitably confront what they lack. Like microbiome writers, however, authors of modern bubble stories change the terms, resurrecting David's legacy even as they rewrite his story to become one of successful emergence. In the stories of today, bubble kids are visited by outsiders who awaken the desire for knowledge, sexual contact, and escape. In an echo of Tod and Gina's cinematic relationship, Madeline meets her worldly neighbor Olly, a black-wearing, girlfriend-having boy from a fractured family; the perfect

counterpart to her cloistered existence with her mother. Eli's visitor is Haley, an adolescent girl wearing black and red, and bearing knowledge of previous inhabitants of the house that haunts him. Hill's Yuki discovers digital traces of a woman of an older generation, a self-assured, lipstick-wearing vision whom she quickly idolizes. And Foster's Joe encounters a nurse willing to bend the rules in order to help him dream of life beyond.

Their visitors trigger in bubble kids a desperate yearning, a sudden intolerance for the membranes that have safeguarded them. Remaining within means reckoning with the same questions that preoccupied the early gnotobiologists: what does it mean to be alive? does alive but suffering count? In the microbiome era, the answer is a resounding no. The repetitive image of physical closeness broken by the germfree barrier focalizes this theme (Figure 18); it recalls both Vetter, who was frequently photographed touching his parents through his membrane, as well as the iconic image of romantic love impeded by the barrier in Travolta's film. Loves and lives are interrupted, rendering the bubble intolerable.

Figure 18. Madeline and Olly (Meghie); Eli with his mother (Foy).

And so, as bubble kids have always done in fiction, they come out. As Madeline writes in a note to her mother, announcing that she is running away with Olly, "I'm not choosing death. It's that if I don't go, I won't really know what it's like to be alive" (Meghie). Madeline's cohort makes the same choice. Eli torches the clean house; Joe organizes a brief nighttime escapade with the nurse; Yuki emerges to ride bikes with the neighbors she's watched for so long. In every case,

bubble kids choose germs as the fair price for the assertion of independence, casting off the parental and medical strictures that have thus far kept them inside. Stepping into the germy world is an act of coming into their intellectual maturity and, in some cases, sexual maturity.

Yet where earlier stories of germfree enclosures took isolation to be the mark of a wayward society, here the story is rewritten for a time in which the absence of germs is biologically unthinkable—in which the fear of disease no longer holds sway. The culprit is smaller in scale: an individual's failure to apprehend the microbial world as fundamentally safe. Modern bubble kids are victims of elaborate hoaxes, having been led to mistake the nature of the threats they face. It is the germfree state itself, and not their immune systems, that they must fear. In this sense, their stories echo Rodney Dietert's transformation of David from SCID patient to victim of a missing microbiome. For contemporary bubble kids in fiction, the germs are what count.

In 2001's *Bubble Boy* film, protagonist Jimmy Livingston daringly escapes his bubble in the name of love, only to find that he's actually fine—his confinement was merely the consequence of his mother's outsized germophobia (Hayes). While *Bubble Boy* plays that revelation for laughs, the same maneuver underlies a more serious reckoning with germs in later examples. *Everything, Everything* also encloses its young heroine on the basis of maternal germophobia. Madeline undertakes her escape on the same terms as Tod—risking illness in the name of love—only to find that she too survives. Yoon neutralizes the threat of microbial risk by depicting her protagonist's SCID diagnosis as a figment of her overprotective mother's imagination. The same is true in *Eli*, in which the sick boy learns that he is not sick, either; his diagnosis is satanic parentage, a problem that the film ultimately finds more solvable than germfree suffering. In an adjacent but illustrative example, the illustrated children's book *My Germfree Bubble Pets Go Camping*, resolves microbial threats by simply ignoring them. The story's young narrator explains that his germfree dog and cat live in

bubbles to remain safe and that if the bubbles crack they could sicken and die (Figure 19) (Bernal and Ansolabehere). During the camping trip, the pets run off in the middle of the night, reappearing later with ominously cracked bubbles. And then, absolutely nothing happens: everyone goes happily home, neutralizing the microbial threat in a cheerful contradiction of the book's very premise.

Figure 19. Do they really need these bubbles? Jaxx and Felicity in My Germfree Bubble Pets Go Camping (Bernal and Ansolabehere).

In each case, the microbial world is rendered safe, reinforcing the microbiome-era sentiment that life without germs is rather impossible, after all. The germfree barrier, imprisoning inhabitants on the basis of germ threat, has fallen. Microbes simply aren't scary anymore. As teenagers and bubble pets step out of their protective bubbles, they model what microbiome science and popular science have been saying this whole time: that to live without germs is to live a shadow of ourselves.

5. Conclusion

The specter of germfree life haunts our dreams of the future. As this chapter has shown, in microbiome writing the miseries of microbeless bodies—whether animal or human—reflect onto the present. Authors identify the deformities of the germfree mouse, or the social ruptures of David

the Bubble Boy, as the terminus of a trajectory already in progress. Glimpsing our own germfree futures, microbiome writing suggests, we are compelled to intervene.

In this context, it is unsurprising that microbiome writers unanimously suggest ways of emerging from the bubbles of our modern, sanitized existence. They champion responsible means of rewilding bodies devastated by antibiotics, whether through consumption of fermented foods, through "natural" ways of birthing and feeding babies, or through the dictum to *get your hands dirty*. As we have seen, not only human bodies but the very functioning of society and community are at stake. In the post-microbiome vision of the future, we step out of our bubbles, awaken from the dream, and build for ourselves better, and germier, lives.

This awakening carries particular obligations for expectant mothers poised to deliver babies into a germy world. Within microbiome discourse, as the following chapter shows, has emerged a particular form of bodily policing that harnesses the moral force of gnotobiotic life and literature to determine how babies ought to be born. Carrying sterile fetuses preparing to transition into microbial symbiosis, mothers must safeguard the lessons of David Vetter, of germfree animals, and of germfree fiction, taking on the task of delivering their children safely into their microbial birthright.

Works Cited

Anderson, Scott C., et al. *The Psychobiotic Revolution: Mood, Food, and the New Science of the Gut-Brain Connection*. National Geographic, 2017.

Ankeny, Rachel A., and Sabina Leonelli. "What's so Special about Model Organisms?" *Studies in History and Philosophy of Science*, vol. 42, 2011, pp. 313–23.

Bernal, Mitchell, and Martin Ansolabehere. *My Germ-Free Bubble Pets Go Camping*. Kreations, 2008.

Blaser, Martin J. Missing Microbes: How the Overuse of Antibiotics Is Fueling Our Modern Plagues. Henry Holt and Company, LLC, 2014.

Blashfield, Jim. *Paul Simon - The Boy in the Bubble (Official Video)*. 1986, https://www.youtube.com/watch?v=Uy5T6s25XK4.

Bud, Robert. *Penicillin: Triumph and Tragedy*. Oxford University Press, 2007.

Carter, Philip B., and Henry L. Foster. "Gnotobiotics." *The Laboratory Rat*, edited by Mark A. Suckow et al., 2nd ed., Elsevier, 2006, pp. 693–710.

Charles River. *The Germ-Free Factories*. 2019, https://www.criver.com/eureka/the-germ-free-factories.

Collen, Alanna. 10% Human: How Your Body's Microbes Hold the Key to Health and Happiness. Harper Collins, 2015.

Davies, Gail. "Mobilizing Experimental Life: Spaces of Becoming with Mutant Mice." *Theory, Culture & Society*, vol. 30, no. 7/8, 2013, pp. 129–53.

DeLillo, Don. "The Black-and-White Ball." *The New Yorker*, Dec. 1996, https://www.newyorker.com/magazine/1996/12/23/the-black-and-white-ball.

---. *Underworld*. Scribner, 1997.

Dietert, Rodney. The Human Superorganism: How the Microbiome Is Revolutionaizing the Pursuit of a Healthy Life. Dutton, 2016.

Dunn, Rob. The Wild Life of Our Bodies: Predators, Parasites, and Partners That Shape Who We Are Today. Harper Collins, 2011.

Elman, Julie Passanante. Chronic Youth: Disability, Sexuality, and U.S. Media Cultures of Rehabilitation. New York University Press, 2014.

Falk, Per G., et al. "Creating and Maintaining the Gastrointestinal Ecosystem: What We Know and Need To Know from Gnotobiology." *Microbiology and Molecular Biology Reviews*, vol. 62, no. 4, Dec. 1998, pp. 1157–70.

Foster, Stewart. *The Bubble Boy*. Simon & Schuster Childrens Books, 2016.

Foy, Ciaran. *Eli*. Paramount Pictures, 2019.

Gannon, Robert. "Life in a Germfree World." *Popular Science*, Aug. 1962.

Gordon, Helmut A., and Laszlo Pesti. "The Gnotobiotic Animal as a Tool in the Study of Host Microbial Relationships." *Bacteriological Reviews*, vol. 35, no. 4, Dec. 1971, pp. 390–429.

Gustafsson, Bengt. "Germ-Free Rearing of Rats: Preliminary Report." *Cells Tissues Organs*, vol. 2, no. 3–4, 1946, pp. 376–91.

Hayes, Blair. *Bubble Boy*. Touchstone Pictures, 2001.

Herrell, Wallace E. "Thoughts on the Role of Gnotobiotics in Clinical Medicine." *Germfree Research: Biological Effect of Gnotobiotic Environments*, edited by James Heneghan, Academic Press, 1973, pp. 9–17.

Hill, Jenni. "They Want to Live Too." *Infectious Futures: Stories of the Post-Antibiotic Apocalypse*, edited by Brigitte Nerlich and Matthew Clarke, Nesta, 2015, pp. 27–32.

Hoy, Suellen. Chasing Dirt The American Pursuit of Cleanliness. Oxford University Press, 1996.

Kirk, Robert G. W. "'Life in a Germ-Free World': Isolating Life from the Laboratory Animal to the Bubble Boy." *Bulletin of the History of Medicine*, no. 86, 2012, pp. 237–75.

---. "'Standardization and Mechanization': Germ-Free Life and the Engineering of the Ideal Laboratory Animal." *Technology and Culture*, vol. 53, no. 1, Jan. 2012, pp. 61–93.

Kleiser, Randal. The Boy in the Plastic Bubble. 1976.

Knight, Rob. *How Our Microbes Make Us Who We Are.* https://www.ted.com/talks/rob_knight_how_our_microbes_make_us_who_we_are?language=en. TED2014.

Landecker, Hannah. "Antibiotic Resistance and the Biology of History." *Body & Society*, 2015.

Lang, Allen Kim. "World in a Bottle." *Galaxy Magazine*, Oct. 1960.

Levine, Jerry. "Mr. Monk and the Garbage Strike." *Monk*, Season 5, Episode 2, 14 July 2006.

Luckey, Thomas D. *Germfree Life and Gnotobiology*. Academic Press, 1963.

Meghie, Stella. *Everything, Everything.* Metro-Goldwyn-Mayer and Alloy Entertainment, 2017.

Metchnikoff, Olga. "Note sur l'influence des icrobes." *Annales de l'Institut Pasteur: Journal de microbiologie*, 1901, pp. 631–34.

Nerlich, Brigitte. "'The Post-Antibiotic Apocalypse' and the 'War on Superbugs': Catastrophe Discourse in Microbiology, Its Rhetorical Form and Political Function." *Public Understanding of Science*, vol. 18, no. 5, 2009, pp. 574–90.

O'Malley, Maureen A., and Derek J. Skillings. "Methodological Strategies in Microbiome Research and Their Explanatory Implications." *Perspectives on Science*, vol. 26, no. 2, Apr. 2018, pp. 239–65.

Paxson, Heather, and Stefan Helmreich. "The Perils and Promises of Microbial Abundance: Novel Natures and Model Ecosystems, from Artisanal Cheese to Alien Seas." *Social Studies of Science*, vol. 44, no. 2, 2014, pp. 165–93.

Podolsky, Scott H. The Antibiotic Era: Reform, Resistance, and the Pursuit of a Rational Therapeutics. Johns Hopkins University Press, 2015.

Rader, Karen. Making Mice: Standardizing Animals for American Biomedical Research, 1900-1955. Princeton UP, 2004.

Reyniers, J. A., et al. "Rearing Germfree Albino Rats." *Lobund Reports*, vol. 1, University of Notre Dame Press, 1946.

Rosebury, Theodor. *Life on Man*. The Viking Press, 1969.

Sachs, Jessica Snyder. Good Germs, Bad Germs: Health and Survival in a Bacterial World. Hill and Wang, 2007.

Safire, William. "On Language; Bubble, Bubble, Toil and Transition." *The New York Times Magazine*, 29 Nov. 1992, https://www.nytimes.com/1992/11/29/magazine/on-language-bubble-bubble-toil-and-transition.html.

---. "ON LANGUAGE; The Man in the Big White Jail." *The New York Times Magazine*, 24 Jan. 1993, https://www.nytimes.com/1993/01/24/magazine/on-language-the-man-in-the-big-white-jail.html.

Schoeb, Trenton R., and Richard J. Rahija. "Gnotobiotics." *Laboratory Animal Medicine*, Elsevier, 2015, pp. 1263–96.

Simon, Paul. *The Boy in the Bubble*. Warner Bros., 1986.

Sterling, Bruce. *Schismatrix Plus*. Open Road, 1996.

Tomes, Nancy. The Gospel of Germs: Men, Women, and the Microbe in American Life. Harvard University Press, 1998.

Trexler, P. C., and Louise I. Reynolds. "Flexible Film Apparatus for the Rearing and Use of Germfree Animals." *Applied Microbiology*, vol. 5, no. 6, Nov. 1957, pp. 406–12.

Turney, Jon. I, Superorganism: Learning to Love Your Inner Ecosystem. Icon Books Ltd, 2015.

Velasquez-Manoff, Moises. An Epidemic of Absence: A New Way of Understanding Allergies and Autoimmune Diseases. Scribner, 2012.

Weinstein, Matthew M. "Gnotobiology: Utopias of Science and Adolescence." *Bodies Out of Control: Rethinking Science Texts*, Peter Lang Publishing, Inc., 2010, pp. 17–27.

West, Wallace. "The Incubator Man." *Weird Tales*, vol. 12, no. 4, Oct. 1928, pp. 535–39.

Williamson, Alice P., editor. "A Special Report: Four-Year Study of a Boy with Combined Immune Deficiency Maintained in Strict Reverse Isolation from Birth." *Pediatric Research*, vol. 11, 1977, pp. 63–64.

X-Ray Spex. Germfree Adolescents. EMI.

Yong, Ed. I Contain Multitudes: The Microbes Within Us and a Grander View of Life. Harper Collins, 2016.

Bringing Baby Earthside

A fetus is floating above the earth. Curled into a tucked position, it faces the planet expectantly, its face and limbs illuminated in an ethereal blue glow. This inexplicable astronaut is the poster child for *Microbirth*, a 2014 documentary by British producers Toni Harman and Alex Wakeford. The film, which explores contemporary research into the development of the infant microbiota following birth, was extensively circulated in the US at a time of peak public engagement with human microbiome research. The film asserts a generational urgency for attending to the nascent microbiome, as captured in the poster's proclamation that the film will "[reveal] the microscopic events during childbirth that could hold the key to the future of humanity."

The child featured on the *Microbirth* poster is also the cinematic echo of another astronaut baby, the reincarnated David Bowman of Stanley Kubrick's *2001: A Space Odyssey*, who in the film's closing sequence is transformed into the film's iconic star child, observing his home planet with a wide-eyed and impenetrable gaze (Figure 20). Bowman's return to Earth is the culmination of a sweeping trajectory of human progress, an evolutionary narrative tracing an arc from prehumans to a spacefaring society and beyond as driven by technological and ecological dominion.

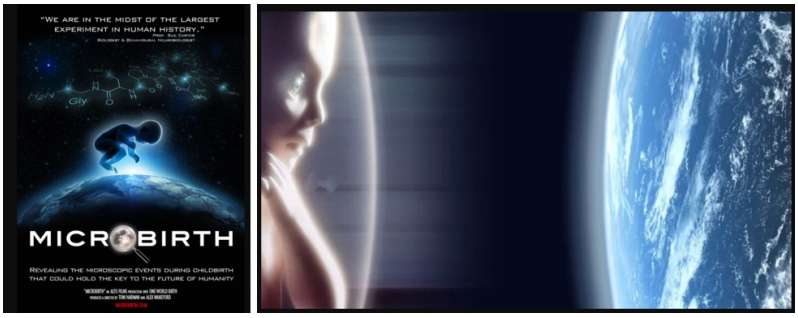

Figure 20. Star children: Harman & Wakeford's Microbirth (2014) and Kubrick's 2001: A Space Odyssey (1968).

This other, more recent star-child of *Microbirth* also represents a civilizational-scale narrative, though it bears a different relationship to its home planet. The film, which makes a trenchant

argument for the importance of securing a baby's future health through the transfer of a mother's vaginal microbiome in childbirth, invokes Kubrick's image as part of its thematic linking of individual and planetary ecosystems. *2001* presents a confrontation between Bowman and a human species that had culminated in orbiting nuclear weapons; progress ultimately imperils human survival. In *Microbirth*, while modern technology also signals peril, it represents not a continuity but rather a severing of the evolutionary past through Cesarean delivery and other birth interventions. *Microbirth*'s space imagery functions to condemn the trajectory of progress altogether, suggesting that this spacefaring society needs to come home, to reject the technologies and ecologies it had sought to master, and to become human again by reintegrating with microorganisms on a damaged Earth. Mothers, the film suggests, are centrally responsible for correcting the wayward course of human ambition, for, as Rebekah Sheldon has written, "saving the world through childbirth" (56). Vaginal delivery hearkens back to an earlier, better time; it operates in the service of "a nostalgic past that each individual must labor to restore in the future through childbirth" (Sheldon 57).

That sovereign reproductive task is also articulated symbolically in the *Microbirth* star-child's visual genealogy, through which it functions as a touchstone for reproductive politics and questions of women's autonomy. Floating in space rather than amniotic fluid, lacking a placenta and therefore separated from any familial or maternal context, it is an instance of what Scott F. Gilbert and Rebecca Howes-Mischel have termed "the public fetus": a visual iconography arising from Lennart Nilsson's fetal photography of the 1960's. They argue that "the image of the 'autonomous fetus' abstracts the fetus from the mother, the womb, and from all social contexts, thereby emphasizing 'individuality'" (377). This abstraction has enabled the public fetus' recruitment by anti-abortion activists, who have taken it as visual evidence of fetal personhood. Kubrick's star-child had previously taken on this same role: as Zoë Sofia has observed, the film's deep suffusion by

reproductive imagery presents the Bowman-fetus, strangely living unaided in space, as an act of masculinized reproduction that would become deeply resonant with the anti-abortion stance (56).[62]

The *Microbirth* baby follows in these visual footsteps. Placentaless, motherless, and timeless, it too symbolizes normative standards of mothering, embodying deeply gendered and regressive messages about a woman's obligation to her developing fetus. Lauren Berlant has written that as Nilsson's fetal photographs circulated anew in the 1990s, they insistently "evaporate[d] the mother," visually symbolizing her "political erasure" in service to that decade's ideals of service, nation, and belonging (167-8). *Microbirth* engages in this same work of evaporation, with its poster child signifying an erasure of the mother—in this case, to highlight the microbiota she stands poised to deliver as her child, in a salient bit of natural childbirth parlance, "comes Earthside." While mothers have long been asked to sacrifice their own desires in order to grow, birth, feed, and raise healthy little humans, microbiome discourse brings to these obligations a novel material basis. As scientists, journalists, and natural childbirth advocates have latched on to microbiome science, mothers have once more disappeared, this time into the teeming hordes to which their pregnant bodies are host.

Indeed, across contemporary microbiome discourse, female bodies are perennially receding from view. As scientists and authors bring into focus the microbiology of the reproductive tract and of childbirth, actual maternal bodies often disappear. This typifies a gendering that has marked microbiome discourse from the start. The media blitz that accompanied the first results of the Human Microbiome Project in 2012 had already defined the microbiome in relation to the female body. Consider the lead image for *Scientific American*'s exultant report on these first results, which renders a woman's body in diverse microorganisms: as her microbes become visible, the woman herself disappears (Figure 21) (Ackerman). The microbiome, the image suggests, is feminine—or at

[62] For a historical overview of the anti-abortion movement, see (Holland). On the anti-abortion movement's relationship to fetal imagery and fetal autonomy, see (Hopkins et al.), (Morgan and Michaels), and (Petchesky).

least, it inhabits a female body. Note as well that this woman-microbe cloud is headless; her brain is beyond the range of the image. Defined by her microbial contingent, she disappears in both body and mind.[63]

Figure 21. The microbiome, defined from the start as a feminine entity (Ackerman).

She disappears most dramatically, however, in regards to her reproductive function. Broadly across the texts and images of the microbiome era, pregnancy and early motherhood are framed as *microbial* more than human events. A 2016 article in *The New Yorker*, for instance, is titled "Breastfeeding the Microbiome," a phrase that erases both mother and baby as embodied humans, in deference to the virtuous nurturing of the microbiome itself (Yong). Tasked with delivering and cultivating her child's microbiome, the mom who dutifully recedes from view in setting aside her own preferences and comfort becomes a "microbial mother" (Houf), a vessel determined to pour herself out for the next generation. Even if, as Chikako Takeshita has argued, the growing understanding of fetuses as coemerging with the maternal microbiome undercuts pernicious claims of fetal autonomy, it still too frequently dissolves the mother herself.

[63] For further analysis of the gendering of similar microbiome images from this era, see (Houf). These images visually evoke the history of anatomical images in the vein of Vesalius, with their exposed muscles and blood vessels. Like contemporary microbiome images, anatomical diagrams are female in essence: as Katherine Park has argued, the masculine bodies depicted in classical anatomy were in fact based on female bodies that served invisibly as "the paradigmatic object of dissection" (81).

In the texts I discuss in this chapter, the disappearing-mother motif undergirds a moral injunction to "microbirth" the next generation. I analyze scientific and cultural texts discussing the transfer of microorganisms from mother to baby during delivery, from 2010 to present. During this period, nascent research into microbiome seeding at birth developed into a robust field while natural childbirth advocates increasingly transformed the research into statements of maternal obligation. And as scientific texts subtly recruited and rewrote narratives of microbial belonging on a germy planet, the duty to responsibly seed a newborn's microbiota deepened into an argument for a mother's obligation to the microbial planet itself.

Microbial motherhood is consistent with other contemporary invocations to live with germs. The past decade's public emphasis on probiotic eating, fecal transplants, rewormings, and more all share an ideal of "deliberate reentanglement," to take Jamie Lorimer's term: the belief that taking on a particular microbial contingent can reverse the devastations of antibiosis and confer a wellbeing found only in symbiotic association with our microscopic allies. Among these forms of reentanglement, perhaps no practice is as heavily researched, discussed, and obsessed over as childbirth. Since 2010, medical researchers, birth professionals, journalists, and expectant parents have collectively immersed themselves in the science of obstetric microbiomics; the topic features regularly in microbiome popular science writing, from books to blogs, from midwifery magazines to news reports. Increasingly, how a child acquires its first microorganisms is made to matter.

In the past decade, microbiome research has tangibly reshaped birth practices as pregnant women seek to deliver babies into their full microbial endowment, safely bringing their voyager fetuses Earthside.[64] Especially within the natural birth community, a microbially-conscious

[64] The changes have been so rapid and drastic that scientists and obstetric organizations have repeatedly sought to correct course, challenging the hype as running ahead of the science and questioning the risks involved in taking on as-

pregnancy is said to ensure a future of radiant health, whereas the disruption of the microbiota in early life leads to a grim future of dysbiotic, chronic disease. And so mothers are charged with rejecting aseptic birth practices like perinatal antibiotics, formula feeding, and hospital birth; and with undertaking microbe-cultivating practices like breastfeeding, skin-to-skin contact, and more. Above all, they are newly accountable for the role of microbiota transfer in delivery itself. Birth discourse frequently exalts vaginal delivery, in which a newborn arrives through the microbially-rich birth canal, as superior to the aseptic procedure of Cesarean section, in which a child's first inoculation comes from environmental microbes. The choice between vaginal delivery (VD) and Cesarean delivery (CSD) thus becomes the most essential decision a mother must make on behalf of her child. In fact, CSD is said to imperil both her child and—as the *Microbirth* poster suggests—"the future of humanity" itself.

For the reappraisal of pregnancy in light of the microbiota has come into being accompanied by the nightmares of germfree speculation and the familiar sentiment that we simply cannot do without our microbes, at any scale. Scientists and popular science writers frequently assert the amniotic sac to be a germfree space, with the first inoculation of the microbiome occurring at birth; mothers preside over the transition between sterility and germiness. Narratives of germfree life and a microbeless Earth structure microbiome-era fears of surgical birth, freighting birth with the full weight of individual and global risk inherited from the germfree imaginary. As she labors to deliver both child and microbiome, the microbial mother is also charged with an obligation to reverse the damages of modernity. The precarious seeding of a newborn's microbiome is also a reparation for civilization's wayward antibiotic trajectory.

---

yet-untested birth practices: for instance, (Stinson et al.) and (Perez-Muñoz and et al.), as well as an official cautionary statement by (American College of Obstetricians and Gynecologists).

Microbiome-era discussions of pregnancy and birth frequently argue that an expectant mother is empowered by attending to the microbiology of birth: armed with microbiome facts, she is prepared to resist surgical birth, formula feeding, and more. Mothers are encouraged to follow their natural instincts, to do what, as one scientific paper states, "mom knows best" (Funkhouser and Bordenstein). Yet particularly through this discourse's engagement with germfree narratives, that promise of empowerment collapses under the weight of obligation to planet and humanity. What "mom knows best" turns out to be no knowledge at all—the laboring mother is just as headless as the image above—but rather an expectation of performing natural childbirth, no matter the cost to herself.

This chapter explores how a scientific and popular science texts articulate the maternal duty to accomplish a natural, vaginal birth, especially in the work of the prominent obstetric microbiome researcher Maria Gloria Dominguez-Bello. A Venezuelan microbiologist co-appointed in microbiology and anthropology at Rutgers, Dominguez-Bello has investigated the microbiology of birth and its most common interventions, including CSD, hospital birth, antibiotic usage, and more. Through her research runs the theme, as she stated in a recent talk, that "in our culture we interfere in every single step of the process." Intervention means *interference* in what is natural; the result is felt at the level of humanity itself, threatening the human microbiome itself "in an age of disruptive change" (Dominguez-Bello 2019).

Dominguez-Bello's influence has been broad and sweeping. As microbiome discourse has solidified around the stance that birth interventions impede the proper development of an infant's resident microbiota, it is almost always her research that is recruited as evidence.[65] A frequent academic speaker and popular science interviewee, her work more than any other has shaped today's

[65] Much to the consternation of the research community: Stinson, Perez-Munoz, for instance, allude to the hype in offering a call for self-correction in the science, so as to steer the public away from interest in risky birth practices.

reassessment of microbial motherhood. In this chapter I confine my analysis to scientific articles, both research papers and commentaries, on which she is first or last author; as well as popular science artifacts in which she is interviewed, including news reports, books, and the documentary *Microbirth*, which centers her research and that of several of her frequent collaborators. Using a close-reading analysis of these objects, I show how they together idealize VD over CSD as mediated through engagement with the tropes and narratives of germfree fiction.

The presumed sterility of the pregnant uterus is crucial to Dominguez-Bello's work and to her frequent assertion that the microbial events associated with labor and delivery affect later patterns of ecological succession, eventually resulting in health or illness. In other words, birth is a membrane-rupture problem in which emergence into a germy world carries moral weight. In articulating the stakes of this transition, Dominguez-Bello et al. reveals a debt to the pioneering germfree imagination of literature, both invoking and rewriting the conventional narratives of germfree fiction: stories of bubble kids and planetary contamination, the risk of catastrophic membrane rupture, of superinfection, of disastrous mis-population. The obstetric event of "rupture of membranes" is broadly equivalent to other germfree ruptures, as the fetus emerges into a germy universe in a consequential and irreversible passage.

Further, it is by reading Dominguez-Bello's work alongside fictional accounts of germfree membrane crossings that the stakes of amniotic rupture come into view. While scholars in the social sciences and humanities have begun questioning the gender norms and policing of women's bodies as focalized by microbiome discourse surrounding pregnancy and childbirth,[66] it is through examining cultural narratives that the full scope of the argument set forth by Dominguez-Bello and colleagues becomes clear: that mothers are accountable for passing on the microbes that make us

[66] See (American College of Obstetricians and Gynecologists) for a feminist analysis of the microbial pregnant body, (Howes-Mischel) on the microbiome and natural childbirth, and (Ayala and Freeman) on the placental microbiome.

human on a planet that they define as primordially microbial. I argue that it is precisely the elision of individuals and planetary ecosystems that entraps mothers in a self-erasing microbiomic aspiration. Guardians and gatekeepers of their children's future microbiomes, they bear the responsibility of seeding their children and also the planet itself, present and future. Cesarean delivery thus presents an epic threat to individual and collective human lives on planet Earth.

1. Becoming Terrestrial

The particular emphasis on vaginal delivery in contemporary baby microbiome research is a new phenomenon. While the development of a baby's microflora has long been the subject of microbiological interest, only with the Dominguez-Bello group has it become seen as so rapid and so determined by the moment of birth. Explicit in this shift is a relocalization of the colonizing microflora such that its conveyance and later development are centered in the maternal birth canal and therefore also in the act of vaginal delivery.

Until recently, the colonization of the infant gut was taken to be a slow-moving and external process. By the mid-nineteenth century it was a point of consensus that the infant microbiota arrived after birth. In 1866, Breslau determined the meconium (first neonatal poop) to contain no culturable microorganisms, with the first arrivals becoming detectable 10-12 hours after birth. By 1885, Theodor Escherich had formalized the study of microbiota development in the infant gut, describing the increasing diversity and quantity of bacteria across multiple time points. For these early bacteriologists, an infant's microbiota were acquired exclusively from the exterior world; the fetal environment was considered to be germfree, a point codified in Henri Tissier's "sterile womb hypothesis" and extensive study of the infant gut. At a time when the essential contributions of the microbiota to human physiology were beginning to be understood, the colonization of the infant gut

seemed both inevitable and necessary. In contrast to today's microbiome rhetoric, however, early bacteriologists rarely if ever attributed the incoming microorganisms to the mother's own microflora. Breslau suggested that they arrived through the mouth while Escherich considered the possibility of rectal introduction, but both sourced colonizing bacteria to the ambient air surrounding the newborn. The microbiota, therefore, was understood to be produced by the wider world, arriving in predictable order with familiar patterns but nevertheless determined by external, environmental encounters.

The assumption that the microflora are environmentally-acquired would be complicated in the 20th century, with increased attention to the bacteria of the female reproductive tract. Microbiologist Theodor Rosebury, author of the first comprehensive catalogue of "microbes indigenous to man" in the 1960s, enumerated the vaginal microflora and noted its role as first microbial contact for the newborn baby. Writing for a generation that he saw as overly obsessed with cleanliness, vaccines, and antibiotics, he sought to normalize the human-associated microflora and its origination in the "crucial" moment of "the advent of microbes" at birth (Rosebury, *Life on Man* 34, 33). Noting that the fetus "has no microbes in its sheltered state," he writes that during birth the baby "begins at once to pick up microbes that grow" in the birth canal (33).

While recognizing the inevitability of the maternal microbiota transfer, Rosebury ultimately constrains the impact of this first inoculum: it is simply the first step in a lifetime of "picking up microbes." Rosebury takes a long view of environmental influence, suggesting that neither birth canal nor hospital environment is definitive of a baby's microbiological development:

> The microbes arrive slowly … and normally this first contingent is small. The microbic population that will come to inhabit the new human arrival on earth is by no means simply a hand-me-down from mother to babe, and the notion that the infant is blanketed with

> microbes on contact with infested air is entirely wide of the mark. Microbes there are, certainly; but the mother's birth tract is normally only lightly settled, and the initial environment of hands and air and blankets is likely to range from clean to nearly, if never quite, sterile. (33)

This process of microflora development is largely similar to Rosebury's nineteenth-century predecessors, identifying the external world as the primary source of colonizing microorganisms. He emphasizes that incoming bacteria are acquired through eating and exploring, but most significantly through human contact. For Rosebury, the human microbiota are simply that: human. "The baby," he insists, "does not simply acquire its microbic population from its mother during the process of birth … it must get it later from other people."

Understanding the microflora to be acquired predominantly from the wider human world, it is perhaps unsurprising that Rosebury would turn to planetary metaphors to articulate the relationship between human body and microbial space. Indeed, his writings establish (for the first time, as far as I can tell) the multifaceted planetary metaphors so prominent in today's microbiome discourse: a key precedent for Dominguez-Bello's elision of local and global obligation in childbirth.

An animating conceit of Rosebury's work, evident in his popular science book's title—*Life on Man*—is that the newborn is like a planet to be colonized by incoming microbes. Taking bodies to be landscapes or planets, he routinely describes incoming microorganisms as "settlers" or "immigrants." There is also the reverse directionality in Rosebury's writing, in which the *child* arrives into a microbial planet, an immigrant into a preexisting "microbic world" (33) or "world of microbes" (35). In birth and infancy, a child's microbial colonization renders them ecologically continuous with a planet constituted by those microbes. He writes: "When the time comes, [the fetus] breaks through into contact with the world outside, shedding its aquatic habitat together with

amnion and placenta, and becoming terrestrial, much as a tadpole does when it grows into a frog" (33). In Rosebury's metaphorical framework, "becoming terrestrial" means incorporating terrestrial microbes into a porous body that continually selects those which are adapted to human life. Entering into a microbial planet, Rosebury's baby experiences terrestriality as a developmental process of gradual acclimation to life in a germy world.

By the early 21st century, microbiologists would develop much more robust understanding of the microbial events surrounding pregnancy, birth, and early life. With metagenomic sequencing, is now possible to examine the microbial populations of baby and mother at different body sites and to trace community structures as they change in response to birth-associated events and exposures.

The public's perception of neonatal microbial development, and the impact of birth interventions on it, has been especially influenced by Dominguez-Bello and colleagues' early research on the distinctive microbial profiles of babies born by CSD and their suggestion that those early discrepancies matter across the lifespan. The pivotal paper arrived in June 2010, in the influential open access journal *PNAS*. Published two years before the first results of the HMP, it has had a crucial impact on the frenzied public interest in baby microbiomes. In this small study, researchers examined differences in the microbiomes of infant-mother pairs at multiple body sites, for both CSD and VD babies. They found evidence for persistent differences in microbial communities associated with delivery mode: bacterial communities of VD babies resembled their mothers' vaginal microflora, whereas CSD babies harbored bacteria more reflective of skin communities. The paper additionally reports that mothers who delivered vaginally possessed microflora more similar to their own infants' microflora than to those of other VD babies, a finding

that they suggest indicates "vertical transmi[ssion]" of microbial communities "unique to each mother" in the birth canal.

Encoded in the paper is a subtle inversion of preceding conceptions of environmental influence on microflora development. Based on their results, Dominguez-Bello and colleagues write that "the mother's vaginal microbiota provides a natural first microbial exposure to newborn body habitats"(11972). Here the acquisition of microbes in the birth canal is no longer incidental—it is *natural*. In contrast, CSD babies are identified as acquiring their microflora through "incidental exposures to skin bacteria in the hospital environment" (11972). The authors further suggest that the study's inability to match CSD mother-baby pairs based on skin communities indicates "direct transmission" of the early microbiome "from nonmaternal sources" potentially including "fathers or doctors" (11972). Fathers and doctors were not sampled in the study, but their mention here further enforces that the vagina, not the skin, is the natural site of maternal influence on the microbiome. Vaginal birth is natural and maternal; surgical birth is not.

Without the transfer of vaginal microbes, the study suggests newborns to be vulnerable to a threatening microbial world. The paper speculates the absence of vaginal microbes "may, in part, explain why susceptibility to certain pathogens is often higher" in CSD babies. For example: "64 to 82% of reported cases of methicillin-resistant *Staphylococcus aureus* (MRSA) skin infections in newborns occurred in Cesarean-delivered infants" (11972). In 2010, MRSA was widely identified as a new, scary "superbug" and so the choice to reference it here creates a particularly threatening impression of the microbial world beyond the womb.[67] Conversely, the vaginal microbiota are credited with warding off hostile invaders: "The direct transmission of the vaginal microbiota to the baby may serve a defensive role, occupying niches and reducing colonization by MRSA and other

[67] E.g., NPR's article titled "MRSA: The Drug-Resistant 'Superbug' that Won't Die" (McKenna).

pathogens as site-specific communities develop" (11972). These early events are suggested to have lasting health consequences, due to "differences in the microbial succession patterns … that persist over time" (11972).

Rosebury had envisioned birth as inaugurating a gradual process of "becoming terrestrial" in a microbial world that he defined as generative and fundamentally humane in its conferral of the germs we acquire "from other people." For Dominguez-Bello and colleagues, in contrast, the moment of birth is pivotal; delivery mode is the distinguishing feature of a child's microbial development and future health. The wider microbial world becomes the enemy, endangering a child's healthy development if encountered without the "defensive" microbes of the birth canal. Becoming terrestrial is now only safe within the context of passage through the birth canal, where maternal microbes shield the infant from raw exposure to the external microbial environment.

The benevolent generativity Rosebury had previously attached to the microbic world is now reassigned to the vagina. In the adjacent popular science literature it is evident how much has changed in recent years. The birth canal that Rosebury had seen as "only lightly colonized" is now teeming with life, bacteria crowding round to greet the new arrival. For instance, *Microbirth* producer Toni Harman writes on the *Scientific American* blog that vaginal colonization is like a "big party to take place in the baby's gut":

> As soon as the mother's waters break … the party doors swing open, the stereo is switched on and the first VIP party guests flood in. Suddenly the baby is exposed to a wave of the mother's vaginal microbes that wash over the baby in the birth canal. They coat the baby's skin, and enter the baby's eyes, ears, nose and some are swallowed to be sent down into the gut.

Here, and broadly across popular science writing on birth microbiomes, the vagina houses a welcoming mass of friendly germs. The birth canal is a site of potentiality, carrying the seeds of a generative future.

A competing view brings into focus the shift underway in Dominguez-Bello's reassessment of neonatal microbiome colonization. In a pair of recent commentaries, microbiologist Lisa Stinson and colleagues have contested the 2010 study's assumption that the distinctive microbial profiles of CSD babies are the result of delivery mode itself. They observe that the study does not account for the influence of other microbial disruptions often associated with surgical birth, including antibiotics and delayed breastfeeding, arguing that "while Cesarean delivery is certainly associated with alterations in the infant microbiome, the lack of exposure to vaginal microbiota is unlikely to be a major contributing factor" (1).

Stinson et al. offer a provocative alternative to the sterile womb paradigm and what they sardonically term the "bacterial baptism" thought to occur at birth.[68] They advocate instead for an in-utero colonization hypothesis (IUCH) developed by several research groups in recent years, which together have identified microbial traces in spaces previously thought to be sterile, including the placenta and amniotic fluid. A child's founding microbiome, in other words, might be acquired well before the moment of birth in what Stinson and et al. (2017) take to be an evolutionarily-synchronized process of targeted colonization. They ask: "could commensal or protective bacteria be selectively translocated from the mother to the fetus as part of an active physiological process of fetal microbiome seeding and immune-programing during pregnancy?" (357). Significantly, the

[68] The baptism conceit, invoking a ritual and even superstitious immersion, is more pronounced in popular science discourse surrounding the 2010 study. For example, an expectant father notes in a 2018 NPR interview that "we like the idea of a bacterial baptism instead of a holy baptism — because now she's been initiated with bacteria, friendly bacteria, that should protect her down the road" (Stein).

IUCH model places far less weight on the moment of birth than does its predecessors. Stinson et al. (2018) write that "given recent evidence that microbiome colonization begins *in utero*, the 'bacterial baptism' of vaginal birth might not be as important to microbiome establishment as previously assumed" (3).

Dominguez-Bello has steadily rejected the IUCH, generally by questioning the methodological validity of key studies. Even in recent papers that do allow for the possibility of in-utero colonization, she and coauthors emphasize birth as the principal route of microbiome seeding. Notably, they also tend to minimize the role of microbial acquisition in later infancy; while they view breastfeeding, maternal contact, and more as important contributors to microbiome development, nothing matters so much as birth. Dominguez-Bello is invested in understanding the fetus as developing under germfree conditions, limned by an amniotic sac holding maternal microbes at bay until the rupture of membranes occurs. The fetus is thus poised to enter a germy world, readying for a moment of entry that will determine its microbiological and physiological future.

In other words, Dominguez-Bello's insistence on the sterile womb hypothesis—and her emphasis on the speed and consequence of colonization at birth—transforms pregnancy into a potential membrane-rupture problem resonant with cultural narratives of germfree life. As has always been the case in germfree fiction, the (amniotic) membrane becomes a barrier signifying moral responsibility; it operationalizes the belief that outward passage must be taken in a safe, *maternal* manner. Carrying all the weight that has been historically associated with fictional membrane crossings, this body of discourse frames birth as a consequential, risky passage. It is indeed a bacterial baptism—a ritual immersion that determines an individual's spiritual, or in this case physical, wellbeing.

The similarities are more than incidental. As I'll show, in a wide array of follow-up studies over the next decade Dominguez-Bello and coauthors would recruit the tropes and narratives of germfree fiction, equating CSD with reckless membrane crossings familiar from fiction. Emphasizing the sterility of the gravid uterus, they transform birth into a fable of emergence, a ritual initiation into the evolutionary past. As such, it is also a fable of social progress and maternal responsibility. Much as belief in a healthy future, and scientific authority, kept bubble kids inside their membranes, the safe passage across them has guided contemporary mothers to shape their birth and early parenting decisions around the integrity of their amniotic membranes and their children's passage across them.

2. The Ancestral Wisdom of Vaginal Delivery

Since 2010, Dominguez-Bello and her collaborators have articulated the risks of birth interventions with increasingly dramatic flair. Across a range of papers and popular science artifacts, they define vaginal delivery as binding a child to her ancestral past, both physiologically and culturally, in the context of human evolution on a microbial planet. Delivery mode is therefore a choice between ancient coevolution and modern technology, between the familiar—the familial—and the alien. CSD, as a rupture of human lineage, signifies a microbial colonization that is terrestrial rather than human, upsetting evolutionary wisdom in setting the infant in hostile relation with the external world.

Over the past five years, Dominguez-Bello's scientific texts have repeatedly presented the maternal microbiome as developing in the context of a bacterial planet. Texts in my corpus turn recurrently to the image of a primordial Earth populated by bacterial lifeforms: the origins of life and the origins of the microbiome. In a 2019 commentary in the journal *Gut*, authors explain the

order of events by noting that "bacteria arose about 3.8 billion years ago, and the eukaryotic lineage, which includes humans, arose after the oxygenation of earth's atmosphere 2.2–2.4 billion years ago" (Dominguez-Bello et al. 2019, p. 1108). The scene had previously been given visual impact in *Microbirth*. Early in the film, the narrator asks how modern humans could get so sick so fast. The answer is to "rewind to the origins of life on Earth, to 3.4 billion years ago." Over soaring views of craggy mountaintops, swirling fog, and underwater ocean views (Figure 22), she intones, "bacteria spread far and wide across the planet: in the deepest oceans, in the heart of mountains, in the atmosphere." The film next cuts to Dominguez-Bello herself, observing that "they were first. This is a microbial planet, mostly bacterial, and any other forms of life that came after had to deal with bacteria." Earth is here defined as originally, and thoroughly, microbial; bacteria had inhabited every surface, long before humans' arrival.

Figure 22. "This is a microbial planet, mostly bacterial." — Maria Gloria Dominguez-Bello (Harman and Wakefield)

Time and again, the scientific texts describe the human microbiome as an entity developed in relation to this microbial planet, passed down across generations immemorial in the sweep of evolutionary time. The 2019 *Gut* article notes that "the host-microbiome supraorganism appears to have coevolved and the unperturbed microbial component of the dyad renders host health sustainable. This coevolution has likely shaped evolving phenotypes … on this predominantly

microbial planet" (1108). Elsewhere, papers frequently emphasize the "ancestral" nature of the human microbiome: it is an "ancient heritage," an "ancient assembly" (Blaser and Dominguez-Bello 2016), "our ancestral microbial heritage to which we were exposed through millions of years of evolution" (Dominguez-Bello and et al., "Preserving Microbial Diversity"), transmitted "across of a period of millions of years, representing hundreds of thousands of host generations and untold billions of bacterial generations" (Blaser and Dominguez-Bello 2016). "Humans are more than *Homo sapiens* cells organized in interconnected systems," Dominguez-Bello and Martin Blaser wrote in 201. "Humans evolved in the presence of microbes and coevolved intimate symbioses in microbial organs, where individual populations interacted with other members of the microbial community and with the host" (Dominguez-Bello and Blaser 2011, p. 453).

In each of the above cases, the antiquity of the microbiome is invoked in the context of birth, with a mother's birth canal figured as the site of transmission. The microbes bestowed there, however, are implied to belong to no particular mother—they are universal, ancestral, humane, but not hers alone. Universalizing the microbiome in this way reinforces the disappearing-mothers trend in microbiome discourse. For example, in *Microbirth*, a midwifery professor who has just been informed that there are 10 bacterial cells for each human one, exclaims that "to now think about this *me* which is more microbe than human cells … it's as if it connects me to the universe a bit more." The film then cuts to an image of a galaxy, with the camera zooming in and out among the stars. Birth is then an act of connection to the ancient earth and even to the universe; the celestial imagery is an apt visual metaphor for the film's linkage of planetary and microbiomic history. In the scientific texts, when Dominguez-Bello and colleagues occasionally use the phrases "primordial inoculum" or "primordial birth microbiota," they denote the microorganisms primordial to a nascent human life. At the same time, that adjective once more draws together human and microbe in a planetary milieu.

The microbiota primordial to an individual is also primordial in a greater sense, linking that child to the very origins of Earthly life.

Significantly, though, this primordial human microbiome is distinct from the modern microbial environment of Earth. In an echo of the 2010 paper's suggestion that vaginal microbes provide a "defensive role" in protecting an infant from environmental germs, Dominguez-Bello and colleagues write in a 2015 article that the vagina contributes to a baby's safe arrival on a germy planet, with an evolutionarily-specified task "to protect and promote baby health and provide the newborn with a specific microbial inoculum at birth, before exposure to other environmental microbes" (Mueller et al. 110). The same is true into adulthood: the 2019 *Gut* paper posits that "the microbiota occupies the interface between our bodies and the exterior, and interactions with the environment (including diet, sun-light, bathing, cosmetics) cross this interface" (1108). The result of coevolution on a germy planet, the authors appear to suggest, is a microbiome that affords spatial separation from environmental microbes, that functions as an interface—a shield—guarding against the microbial assaults of Earth. The sense of protective, spatial separation is reinforced in popular science's elaboration of Dominguez-Bello's research. For instance, Ed Yong's interview with Dominguez-Bello: "she thinks that the bacterial heirlooms that babies inherit from their mothers might act as a shield, preventing more dangerous microbes like MRSA from setting up shop" (Yong, "Baby's First Bacteria Depend on Route of Delivery"). Likewise, Carl Zimmer writes that CSD babies may "lack the defensive shield of microbes from their mother's birth canal" (Zimmer).

In this idealization of vaginal birth, the maternal microbiota as passed down across generations provides a safe route of entry for a formerly-germfree fetus arriving into a germy world. CSD threatens to upend this protective function. A child must not arrive Earthside unattended, must not come too close to the wild microbial environment of planet Earth. A child must become

terrestrial—but not too much or too quickly. To do otherwise, as I'll show later, is a violation both biological and maternal.

The ancient and "natural" coexistence of humans and microbes is, of course, a thing always referenced in cultural narratives of bubble boys and gnotobiotic animals. As the preceding chapters show, these narratives perennially set forth the sentiment that "to be human is to be microbial"—that life without germs is an isolation from what makes us human precisely because it disrupts, as Michael Crichton writes in *The Andromeda Strain*, "the evolutionary work of centuries." Dominguez-Bello and her collaborators capture this general sentiment across the corpus of texts under study. More particularly, in their references to coevolution and microbial protection, they restage the events of HG Wells' *The War of the Worlds* and its core narrative of human survival in a germy world. Reading Dominguez-Bello's work through this particular novel helps us to see how much is at stake in framing CSD as a rupture from evolutionary and human history. Specifically, it reveals how obstetric microbiomics identifies childbirth, and expectant mothers, as bearing an obligation to the planetary ecosystem and to humanity itself.

It was Wells who first invoked evolutionary adaptation as a means of affirming the necessity of microbes to human life. In his novel, past generations' endurance of disease has bestowed our continued survival on a microbial planet: "these germs of disease have taken toll of humanity since the beginning of things—taken toll of our prehuman ancestors since life began here." *Here:* in reaching back to the long history of "a billion deaths" enabling humans' survival in the present, Wells defines this survival as place-specific. Death, struggle, and survival on *this* planet have conferred the "resisting power" by which humans survive where the invaders cannot. Germfree and

powerful, the "unearthly" Martians are felled by forgetting their evolutionary past, having rejected their adaptation to the bacterial milieu through which "man has bought his birthright of the earth."

Wells understood this birthright to be a heritable, somatic-line immune system stably passed down from human generation to human generation.[69] Dominguez-Bello's texts apprehend planetary-microbial history differently, transferring this property to the microbiota itself, which it defines as heritable. Across this corpus, authors consistently rely on terms such as "unperturbed" to define an idealized maternal inoculum that is preserved intergenerationally, in the absence of birth interventions. There is an ideal of fixity at work here, most evident in frequent suggestions that the "vertical transmission" of the microbiota at birth is a form of genetic inheritance.

In a 2018 *Science* commentary titled "Preserving Microbial Diversity," Dominguez-Bello and coauthors write that "the microbiome, our 'other genome,' is largely passed from generation to generation, in early life, from mothers to their children" (Dominguez-Bello and et al. 2018, p. 33). Like the human genome, the microbiome is said to be preserved and transmitted intergenerationally through birth. Similarly, in the 2019 *Gut* article, the authors write that "the microbiota has been transferred throughout generations of humans, with the matrilineal line transferring the primordial birth microbiota" (1109). And again: "we inherit the primordial microbiota from our mothers, grandmothers and further on the matrilineal line, with microbial vertical transmission extending back to earlier ancestors" (1109). Microbiome seeding is presented as a transfer rather than an inoculation; a child's first germs bestow an intact replication of ancestral microbiomes. Primordial Earth meets primordial human in an undisturbed "intergenerational handoff" stretching backward in time. This process is metaphorically reified in the popular science discourse surrounding the texts, which often describe vertical transmission through the metaphor of chains. An example is in science

[69] For specific analysis of Wells' conception of the immune system in *The War of the Worlds*, see (Cohen).

journalist Ed Yong's 2016 book *I Contain Multitudes,* where he notes that "the endowment" of vaginal microbes at birth "creates chains of transmission which cascade through generations." For Yong and others, vaginal microbes bind us to our human past.

Dominguez-Bello and colleagues' implication that the vaginal microbiome is a rather fixed entity, inherited whole and unchanged, is echoed in *Microbirth.* The film depicts a multigenerational trio of child, mother, and grandmother holding an outdoor tea party (Figure 23). The narrator explains:

> Science has shown that bacterial populations in the gut are passed on from generation to generation during vaginal birth. So a grandmother has similar bacterial species in her gut as her daughter and even her granddaughter if they all have vaginal births. And so bacterial transfer can be viewed as a kind of bacterial heritage that is passed on from generation to generation from grandmother to mother to daughter.

Figure 23. Bacterial heritage at work (Harman and Wakefield).

More than the microbiome is on the line here: it seems that vaginal birth confers a sort of familial resemblance. The similarity of gut bacteria across generations is also linked with a reproduction of family life. The staging of this tea party, with its performance of maternal bonding and social ritual—the child serving tea, eating snacks, smiling appropriately—reinforces the scientific texts' suggestion that the vaginal microbiome binds babies to the past in extra-genomic ways. Notably,

Microbirth presents that inheritance as being contingent upon VD, transmissible across generations only "if they all have vaginal births." That "if," as the next section will show more fully, suggests that familial and social inheritance are also contingent upon a child's birth.

A figure included with the 2019 paper makes this implication more directly. In this image, Figure 24 below, the maternal microbiome is represented as a fixed indicator of humanity.

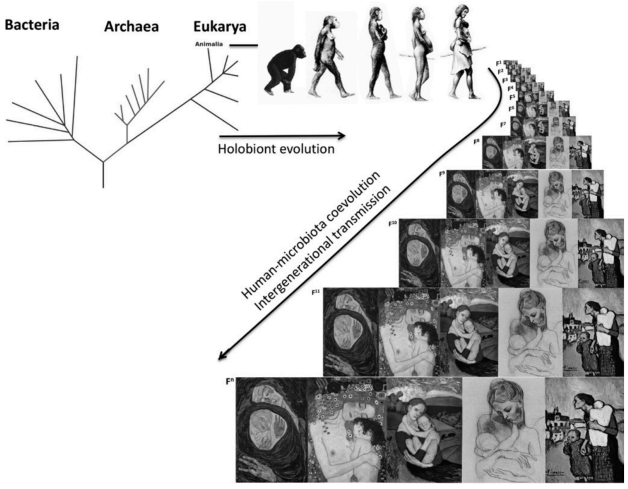

Figure 1 Evolution of the holobiont and vertical transmission through human generations.

Figure 24. Vertical transmission of the microbiome—and much more (Maria Gloria Dominguez-Bello, Godoy-Vitorino, Knight, & Blaser 2019).

It features an array of five paintings mother-baby pairs nurturing their babies and replicates these on successive lines labeled F1, F2 (for successive generations), as traced by an arrow indicating the process of "human-microbiota coevolution" and "intergenerational transmission." The figure defines maternal behavior, such as the breastfeeding and baby-carrying depicted in the paintings, as a distinguishing characteristic of the human species. F1 begins on the top right of the figure, unfolding from the last bipedal figure. Human form (and human culture) are thus suggested to be the pinnacle of hominid evolution. The microbiota are presented as that which separates us from our prehuman ancestors; embedded in the birth canal are the seeds of what makes us human. Further, those

microbiota are implied to be unchanging across the generations, as shown by the exact replication of the five paintings on each successive line.

Read this way, the *Gut* paper's Figure 1 is a visual rendering of the narrative framework of *The War of the Worlds*, presenting the human—as Wells had—as the evolutionary result of life in a germy world. In both cases, coexistence with microbes is vital not only for health and survival but also for the status of humanity itself. Human-microbial symbiosis is represented as the middle step of an evolutionary trajectory that culminates in the germfree Martians. Wells' narrator notes that the Martians are evolutionary descendants of Earthly humans. In contrast, humans have arisen through a process of microbial adaptation dating back to our "prehuman ancestors." The current state of our "resisting power" is therefore positioned on a continuum that that might best be described in two equations:

$$\text{prehumans} + \text{germs} = \text{humans}$$

$$\text{humans} - \text{germs} = \text{aliens}$$

For Wells, and later for Dominguez-Bello, living with germs is a property and condition of the human, uniquely conferring the capacity to survive in our microbial planet. The Martians' downfall at the hands of earthly microbes is thus a triumph of this planet—a triumph of that which protects the human body over the alien seeking to attack it.

By extension, to live outside of that evolutionary context is to become alien. In Dominguez-Bello's texts, the threat of CSD takes shape as an estrangement—an alienation—from a child's human and familial belonging. The "birthright" won by countless human lives is not a given in the modern world: it can be conferred only in the moment of birth and only in passage through the birth canal. Texts in this corpus suggest that one's microbial birthright is contingent upon a mother's birth choices; CSD is a threat to humanity itself. A mother's duty is to ensure the faithful

transmission of the microbiome at birth. As "Preserving Microbial Diversity" states, "we owe future generations the microbes that colonized our ancestors for at least 200,000 years of human evolution" (34).

That sense of obligation is more apparent in the adjacent popular science discourse, which often echoes Wells' language of birthrights to describe the vaginal microbiota as an entity owed to a child by her mother. For instance, the holistic wellness site *Naturally Living Today* suggests that "infants of non-vaginal birth miss the opportunity to inherit their birthright of a healthy microbiome" (Cernohous). *USA Today* borrows the same language in an article on CSD, with an expectant mother commenting that surgically-born babies are "almost robbed of this birthright" (Rudavsky). It would thus seem that a child's microbial birthright is a thing that can be lost (a thing of which a child can be robbed!). It is the mother's obligation to preserve it, to ensure the transmittal of a primordial inoculum that, in binding her child to evolutionary past, will render that child safe in a germy world.

In Wells, the "birthright" bought by generations of death is safeguarded in the genetic inheritance of the immune system; it is "his against all comers." But in Dominguez-Bello's work, the microbial "birthright" is much more precarious, attainable only in the birth canal. If indeed germs are what make us human, then humanity itself is threatened by acts of CSD. Surgical birth stands to rupture a child from its ancestral past and from the protective influence of the germs with which we coevolved. Ancestral heritage stands on the brink with each generation.

3. The Catastrophe of C-section Delivery

In Dominguez-Bello's texts and interviews, the utopian promise of integrating with the microbes that make us human is reserved exclusively for vaginally-born babies. Cesarean birth, by

contrast, is defined as an unnatural rupture that is at once amniotic, maternal, and human. It is represented as the reckless transgression of a germfree boundary freighted with physiological and planetary risk, echoing the fates of reckless membrane crossers in the history of germfree fiction.

This logic is made visual in *Microbirth*, directly after the intergenerational tea party discussed above. The promise of a "maternal heritage" passed down along generations quickly gives way to a bleak alternative. As the film cuts away from the cozy scene of family life to a pond covered in green plants, the narrator asks: "But what if one generation gives birth by Cesarean section?" Two children come into focus, dragging a net through the water. "This could be breaking the chain of maternal heritage." The net appears, dripping, above the water (Figure 25). "Could we be producing a generation of children who are missing vital bacteria?" The scene returns to the view of the pond, revealing that the net has scooped out the plants—has torn a hole in the ecological fabric. CSD is visually equated with intrusion in the natural ecosystem; it excises an organism from its proper home. The narrator concludes by asking whether the lack of vital bacteria "could… be passed down and down for all future generations? What is not known is what the consequences of this might be for humanity."

Figure 25. "Breaking the chain of maternal heritage" (Harman and Wakefield).

In *Microbirth*, the threat of "breaking the chain of maternal heritage" implies a distinct finality; scooping out a neonate means casting it adrift in a germy planet by severing the chains that ought to anchor it to its mother and her ancestors. At the same time, the damage extends beyond

the life of any individual child; a mother's birth choices are made to matter "for all future generations." CSD is a breakage, *Microbirth* suggests, not only of microbiota transfer but also of maternal heritage broadly construed. The film's paired scenes of family picnic and damaged nature emphasize a vision of CSD in which familial connection and social rituals are destroyed, replaced by an empty hole.

Microbirth's scoop-out scene is melodramatic, to be sure, yet this is exactly what is implied in the scientific discourse on which it is based and in which it participates. Dominguez-Bello's papers make the same argument, only more subtly, by linking the vaginal microbiome to the evolutionary past and cultivating a mistrust of the microbial environment beyond the birth canal. If VD endows a child with the microbiological heritage of their ancestors, the reasoning goes, then CSD is a *failure of inheritance*.

And that failure of inheritance falls to the moms. Dominguez-Bello and the wider birth-microbiome community focus in particular on elective C-sections, that is, those that are not medically essential. These are frequently (if subtly) suggested to be the result of maternal oversight or responsibility; it is here that the mother-shaming so prevalent in microbiome discourse takes root. Texts in this corpus and beyond establish mothers as the guardians of their children's microbiota, personally responsible for the quality of their founding inoculum. The precedent for such responsibility had already been established in the cultural legacy of germfree fiction for decades, especially in bubble-kid fiction. Examining such fictions alongside contemporary microbiome discourse highlights how contemporary microbiome discourse equates Cesareans with maternal failure and how it catastrophizes the associated risks.

Fetuses are of course bubble kids in their own right, ensconced in sterile spaces and awaiting a necessary outward passage that they must undertake in order to thrive amongst worldly germs and

people. And as in fiction, passage across the sterile membrane is controlled by the mother. Dominguez-Bello's discourse largely sets aside the role played by doctors, fathers, or circumstance in a child's delivery mode; mothers bear the burden of mediating between natural and artificial birth, and are held accountable for the resulting health outcomes of their children.

In fiction, mothers are almost always responsible for their children's emotional suffering and eventual bubble egress. Even if bubble life is medically necessary, it is still depicted as an unnatural severing of the mother-child bond. Sometimes bubble moms are benignly overprotective, as in the 1976 film "The Boy in the Plastic Bubble," in which Tod's parents follow him everywhere, prompting the adolescent rebellion that drives him to leave. Yet even here his mother assigns herself the blame for his enclosure: at the start of the film, as the newborn Tod is rushed to his bubble, she calls after him, sobbing, "I'm sorry. I'm so sorry." Elsewhere, mothers are more culpable. Sometimes they are absent, leaving their children to fend for themselves in navigating the complexities of bubble life.[70] But more often they are neglectful, controlling, or even deranged. For Wallace West's Columbus Norton, the incubator man, his mother's abandonment explains his "imprisonment" in a germfree enclosure: lacking her protective influence, he falls victim to his father's egocentric pursuit of scientific transcendence. "I have often wondered," he remarks, "what sort of woman my mother most have been to allow her son to be snatched from her so easily. According to the books I have read … mother love is not expressed so" (536). And in the subgenre of bubble hoaxes previously discussed, the failure of "mother love" takes the form of pathological overprotection that serves the mother at the expense of her child. In the horror film *Eli,* for instance, the protagonist's bubble suffering is the price he must pay for his mother's desire to have a child at any cost.

[70] On maternal neglect in bubble fiction: see Fink, Hill, and Foster as discussed in Chapter 2.

For bubble children, the risk of infection is outweighed by the need to assert independence from their absent, overprotective, or deceitful mothers. Membrane crossing is thus a rupture of the mother-child bond, leading them to recognize that their fears were misplaced: it is not germs, but their mothers, that they must reject. Reconciliation is only possible after their mothers demonstrate the appropriate acts of maternal fealty: confession, pain, regret, and the expression of undying love.[71]

In Dominguez-Bello's texts and in popular microbiome writing, mothers similarly preside over a sterile boundary—the amniotic membrane—that is the site of a highly consequential passage. And since the rupture of membranes here occurs well before a child's individuation, the responsibility for how emergence unfolds lies more fully with the mother. Microbially-depleting practices like CSD are generally said to arise from mothers trusting too much in medical intervention and thereby overlooking risks to the microbiome. A 2018 article in *Nature: Scientific Reports* by Combellick et al., on which Dominguez-Bello is last author, advocates for a return to homebirth as a means of restoring the germy practices depleted by hospital-bound birth. The authors write that "hospitalization for childbirth is considered a foundation of safe obstetric care… yet many interventions, such as Cesarean section, are currently overused with the assumption that there are no consequences for mother or baby" (1). It an assumption, they assert, that is only possible when we overlook the importance of the microbiome.

In Dominguez-Bello discourse, such oversights and assumptions are not innocent. The condemnation of Cesarean motherhood I detail below is largely consistent with wider cultural discussions of maternal autonomy in pregnancy and childbirth. As a number of scholars have noted,

[71] In Carole Ann Vetter, the real-world bubble boy's mother, we find the opposite story: one of heroic, sacrificial love and a dedication to her son's growing independence as figured in the iconic image of mother and son touching hands across the plastic membrane. Fiction and film have carried forth the image of hands touching but have replaced the mother with romantic partners. In fiction, it seems impossible to conceive of motherly love and germfree enclosure coinciding. A child's confinement can only be seen as an act of control, manipulation, or selfishness incompatible with the ideal of maternal nurturing.

the actions women take during pregnancy—diet, exercise, alcohol, smoking, etc.—have historically been framed as determining their children's eventual health or illness. Epidemiologist Gemma C. Sharp and colleagues observe that "by implicating the maternal body as a central site for the introduction of health deficits, mothers are positioned as 'vectors' for chronic diseases and intergenerational harms," as exhibited in the tendency toward "alarmist, inflammatory discourse around harms of maternal behaviour to helpless fetuses, to future generations, and ultimately to social welfare" (23). They continue, "in many narratives, pregnant women appear as individually responsible for specific harms to their offspring" (23).[72] Microbiome discourse recapitulates this trend. Saray Ayala and Lauren Freeman have argued that microbiome research is sometimes mobilized as merely a "new site for policing women's bodies," leading to claims of how women ought to cultivate their future children's microbiomes, even as early as adolescence (122). This policing hinges upon a reframing of the stakes in relation to an infant's developing microbiome. Obstetric microbiomics, in fact, intensifies the sense of risk by distilling it into a single moment and single choice: either a mother preserves her microbial heritage, or she doesn't, with intergenerational implications.

In Dominguez-Bello's work and its cultural circulation, vaginal birth is an act of maternal sacrifice and nurturing and C-section an act of microbial neglect in which mothers surrender their protective influence, cutting their children loose from their ancestral history. If bubble kids are developmentally bound to outgrow their parents, asserting their independence through separating from the family unit, then CSD is tragic for its premature separation of moms and babies and its disruption of maternal microbiome transfer. Mothers are held accountable for their children's

[72] See also (Howes-Mischel).

microbiomes; the failure to confer the vaginal microbiomic "birthright" becomes the mark of a monstrous mother.

Across my corpus, CSD is presented as an abdication of maternal responsibility. Dominguez-Bello et al.'s 2010 paper, as noted above, had set the tone for defining the vaginal inoculum as "maternal" and "natural." In later texts, the coding of CSD as nonmaternal or unnatural becomes more pronounced. For instance, in 2016 Dominguez-Bello and Blaser describe the earlier study as identifying a rather universal maternal microbiome, writing that "as expected, babies born vaginally have the greatest similarity to the microbiota of other mothers." In contrast, CSD babies appear microbiomically orphaned, having microbiota "no more closely related to their mother than to any other examined mother" (559). Implicit here is a threat of nonresemblance, of a monstrous birth in which a child is unrecognizable. It is a minor point, to be sure, but one that echoes widely across scientific and popular science discussions of this study.

In the texts I survey, nonresemblance indicates that others have taken on the task of founding a child's microbiota. Echoing the 2010 study's suggestion that CSD babies harbor microbes derived from "fathers and doctors," a 2011 paper in *Gastroenterology* states that the "initial microbiota in C-section babies is provided by other people with whom the babies are in contact. Human-associated bacteria are common in hospital environments, and incidental exposures to skin bacteria in the hospital environment could contribute to the microbiota of C-section babies" (Dominguez-Bello, Blaser, et al., p. 1715). They imply that the mother's proper role as *provider* is being taken on by other, "incidental" parties; the seeding is actively provisioned by alternative caretakers, even if it is subpar. Here and elsewhere, environmental microbes—even when they are human-associated—are found lacking because they are nonmaternal. Further, given natural childbirth discourse's engagement with evolutionary narratives it would seem that such claims posit

a severed connection not only to one's matrilineally-inherited microbiota but also to one's ancestral lineage. As *Microbirth's* pond-scooping scene had also suggested, CSD irreversibly destroys a mother-child bond and so threatens both microbiome transmission and familial belonging. Infants are cast adrift, unmoored from their human ancestors as much as from their microbiome "birthright."

Separation from mom in surgical birth thus carries the weight of familial, as well as biological, estrangement. As in bubble-hoax fiction, this is suggested to be done for the mother's benefit rather than the child's. The scientific texts generally minimize medically-necessary Cesareans in depicting elective CSD as an "epidemic" running out of control, a trend also suggested in Dominguez-Bello's blanket statement that "women don't give birth anymore" (Dominguez-Bello 2019). Especially in popular science's engagement with their research, CSD becomes a choice mothers make in the interests of convenience and fear, or simply through a failure to apprehend the consequences. Much like the overprotective parents of bubble fiction, mothers are suggested to choose for their children a route of presumed safety even as they fail to consider other forms of potential suffering, whether dysbiotic or social.

It follows, then, that even a well-intentioned elective Cesarean is an elective harm: a failure of moral judgment that leads to a child's suffering. This is evident in word choices surrounding the CSD-associated microbiome in scientific texts. While the microbiome changes seen in CSD infants are sometimes described fairly neutrally—as a "perturbation," "disruption," or "alteration"—they are sometimes more directly couched in the language of moral failure. For example: an "impair[ment]," a "depriv[ation]," an "insult," a "compromise" of the now-"suboptimal" and "marginalized" newborn gut (Mueller et al.). Such judgments are compounded in the adjacent popular science discourse, where in the words of *Microbirth* producer Toni Harman, C-section is an act of "shortchanging a baby's microbiome" (Harman).

A glimpse into the internet community of natural childbirth advocates exposes how quickly words and arguments like these can slide into all-out mother shaming. Consider, for instance, the website *My Natural Baby Birth*'s article titled "Are You Seeding Baby's Microbiome? It Will Affect Their Entire Future." Author Sarah Prince suggests CSD to be a choice actively to harm a child's wellbeing: "When a mother electively chooses to have a cesarean delivery, she is also choosing to rob her child of ALL the positive benefits gained from having a vaginal birth" (Prince, emphasis in original). C-section is an act of robbery, one that "may make the difference between a sad and painful life, versus one full of vitality and prosperity." These forms of suffering are emotional as well as physical, reflecting a lifecourse that no sane mother—no "maternal" mother—would ever choose.

While audacious, Prince's argument is internally consistent with Dominguez-Bello's. Elective CSD is maternal failure, with far-ranging implications. It is a decision that brings the child, through "incidental exposure" to germs beyond the birth canal, into a hostile microbial world. And the child, unmoored from its familial and human inheritance, is hapless in the face of the microbial planet with which it collides, unprepared. Lacking the maternal inoculum that would confer safe passage, it is exquisitely vulnerable and precariously open to colonization. The CSD infant is at the mercy of a thoroughly microbial planet, ready to be infiltrated by any passing germ.

Time and again, Dominguez-Bello and coauthors emphasize the speed with which a child acquires its first inoculum. Referencing the CSD babies under study in her seminal 2010 paper, Dominguez-Bello has observed that "we were surprised to see how fast those babies were like magnets, getting skin microbiota" (Dominguez-Bello 2019). The magnet analogy captures the speed and force often associated with environmental inoculation in this body of texts: microbes rushing in, all at once, and sticking. She had made a similar point previously in an interview for Ed Yong's *I Contain Multitudes: The Microbes Within Us and a Grander View of Life*: "The baby's immune system is

naïve at birth and whatever it sees first will start its education. Their immune system might be compromised if they start recognising the wrong guys instead of the normal good ones" (123). Here and in Dominguez-Bello's scientific texts is consistently expressed a profound mistrust of "the wrong guys." Babies are like ducklings ready to imprint on the first germs they see, whether their mother's familiar bacteria or the wild inhabitants of a microbial planet.

Which is, precisely, the risk of reckless membrane crossing in germfree fiction. The threat of the ruptured membrane is the threat of haphazard, lethal encounter with a microbial world. Madeline Whittier, the bubble protagonist of Nicola Yoon's *Everything, Everything* articulates that risk as follows: "If I go outside I would die. It's not that I don't want to go outside. It's that I can't. Simple viruses will kill me" (Meghie). The simplicity of ordinary viruses belies the threat. Elsewhere in fiction, the threat is more graphically portrayed as catastrophic superinfection: Crichton's Kalocin patients, with their jellied brains and liquified stomachs, West's incubator man rendered "100 per cent susceptible to the first microbe which found lodgment in his body" (540), Lang's germfree Lapins dead of bizarre infections within days of their escapes. And, of course, Wells' Earthbound Martians, the pioneering bubble boys, sharing with their red weed the fate of "rott[ing] like a thing already dead."

The same threat of a germfree space colliding with microbes has also long animated fictional and scientific discussions of planetary contamination. In Maurice Renard's "A Man Among the Microbes," for instance, a shattered jar of invasive mushroom spores leads almost instantly to a high-speed overgrowth that destroys the planet's decimated landscape. Similarly, the introduction of Earthly microorganisms into other planets has long been a concern of space travel because it can threaten the destruction of native ecosystems as well as scientific research. This is especially true where those planets are germfree or where later terraforming efforts are to take place. Everywhere

from Kim Stanley Robinson's *Red Mars* to Murray Leinster's *Planets of Adventure* to Ian McDonald's *Chaga*, nothing else is possible unless the microbes are gotten right at the very beginning. There is no going back from the first inoculation. More broadly, the risk of transgressing a microbial boundary is amplified by the parallel risk of exposure that pervades science fictions about people in space. Cities are enclosed in tents, spacesuits made airtight in order to keep the oxygen in and the radiation (and microbes) out. Punctures mean death.

In fiction, as in science: the same threat of deadly influx upon the rupture of membranes drives both Dominguez-Bello's representation of the germfree fetus and these cultural precedents heightening the sense of the risk it faces. The *Microbirth* poster fetus, drifting in its amniotic ether, encapsulates this threat: as it comes Earthside, it faces an onslaught of worldly microorganisms that threaten to overwhelm it. Only its mother's microflora can adequately terraform this child, protecting it by ensuring that its microbiome is built safely from the ground up.

And the impact will be felt forever. "It could make a difference for the rest of their life," Dominguez-Bello told Yong (*I Contain Multitudes,* 123). Indeed, throughout the texts of this corpus, a child's future is suggested to be "determined by maternal-offspring exchanges of microbiota" (Mueller et al. p. 109). The kinship with membrane-crossing fiction is evident here as a future orientation in which a child's eventual state of health is determined by its first exposure; delivery mode carries the weight of a child's future. *Microbirth* goes further, with Rodney Dietert asserting that birth is "the single most important event that's going to chart the course for whether that baby … experiences a lifetime of health," or instead, a lifetime of disease. The immune system, he insists, has "one chance to do this. One chance for optimal human health."

It is important to note that the connection between delivery mode and later health outcomes has not been fully established. Lisa Stinson, who as stated above ascribes to the in-utero

colonization hypothesis, argues that there is insufficient evidence to conclude that the negative health outcomes associated with CSD are directly explained by delivery mode. She and her coauthors take specific issue with claims by Dominguez-Bello's group and others that CSD produces an "abnormal establishment of the early-life microbiome," which then "is the mediator of later-life adverse outcomes" (1). And they note that this presumed connection is widespread: "the perception among the public and medical health professionals alike is that CS delivery deprives the infant of exposure to vaginal microbiota and this leads to neonatal dysbiosis and increased risk of poorer health outcomes" (8). They argue that this perception results from an overlooking of other colonization events in a child's life, with the near-exclusive focus on delivery mode leading patients and practitioners to engage in various risky reparation strategies.

The choice to frame the moment of birth as the microbiological inflection point of a child's entire life is thus not a default. But it is consistent with the logic that spans this corpus, in which CSD is presented as irreparably catastrophic and therefore a mother's duty to prevent. Defining birth as a high-stakes passage between germfreeness and germiness confers upon mothers the obligation to deliver their children—to "microbirth" their children—into their ancestral, microbiological birthright, and into a lifetime of radiant health.

But what, exactly, is the cost to a child of bypassing the birth canal? As I have been showing, Dominguez-Bello's papers and interviews borrow the themes and narrative structure of germfree fiction, with its gruesome and rapid deaths, to define CSD as a massive microbiological risk that must be avoided at all costs, with an individual's and indeed an entire species' wellbeing on the line. Yet the actual threat is something rather less dramatic.

When a newborn is colonized by "the wrong guys," the primary threat is not of infection but instead of noncommunicable illness—the diseases of dysbiosis. Prolonged, chronic suffering looms. A 2014 article in *Trends in Molecular Medicine,* suggests that "disrupting the mother-to-newborn transmission of bacteria by C-section delivery may increase the risk of celiac disease, asthma, type 1 diabetes, and obesity in the offspring" (Mueller et al. 109). The list lengthens across other articles: allergies, autism, inflammatory bowel disease, and more. Such formulations, which are common across microbiome discourse generally, are often presented in the form of the epic catalogue as I have discussed in earlier chapters. However, unlike the missing-microbes threats detailed in microbiome books and popular science articles more broadly, here the risk is shifted to childhood. Dominguez-Bello and colleagues continually emphasize the time-critical nature of the first inoculum. For example, they warn that CSD and other birth interventions produce microbiomic perturbations "at the earliest time in life, exactly the period of maximal metabolic, immunologic, and cognitive development" (Blaser and Dominguez-Bello, p. 560). There is a sense that childhood is a particularly consequential time to be perturbing the microbiota: elsewhere early life is referred to as a "critical window of early-life development" (Dominguez-Bello and et al. 2018, p. 33).

And with that comes the prospect of a lifespan of suffering. There is no quick, gruesome death as in fiction but rather the prolonged suffering of a damaged microbiome inaugurated by a mother's shortsighted birth choices. Yet it is equally decisive. Like the bubble-transgressors of fiction, the hapless CSD babies of Dominguez-Bello discourse experience permanent effects. Once again, it is *Microbirth* that exposes the underlying logic, with Dietert claiming that birth is "the single most important event that's going to chart the course for whether that baby becomes complete and whether that baby experiences a lifetime of health versus a life filled with disease for that child." And later: "children are essentially programmed … for the appearance of subsequent chronic

diseases." As Howes-Mischel has observed, for Dietert in this moment "the maternal microbiome is no longer an environment that *contributes* to fetal-infant development, but one that *determines* life course outcomes" (115).

The projected suffering is also suggested to include miseries exceeding physical ill health. In *Cell Host & Microbe* in 2016, Blaser and Dominguez-Bello speculate that "because microbial products confer odors," and maternal odors are recognized by newborns, CSD then raises "intriguing hypotheses about roles of the microbiota in mother-baby bonding" (2016). Once more, the relationship between mother and child is suggested, without evidence, to be insufficient where surgical birth is involved. Elsewhere is speculation about potential neurological effects—Dietert, for instance, suggests in *Microbirth* that initial colonization of the newborn "affects the brain" and a number of neurological problems can result in ways that produce behavioral problems.[73]

Getting the microbes right, then, is said to be a required for the optimal development of physiological health as well as maternal bonding. The germfree voyager baby is a hapless victim of whatever germs it first encounters, having "become terrestrial" in a hostile world populated by worldly microbes that are unhealthy, foreign, and fundamentally inhumane. And because Dominguez-Bello and colleagues define the vaginal microbiome as a heritable, vertically transmitted entity, the consequences matter forever: not only across a child's lifespan but also intergenerationally for all of one's future descendants. Vaginal birth is a sacrifice one makes in the name of the future.

4. Cesarean Birth in a Post-Microbial World

In Dominguez-Bello's texts and interviews, a mother's birth choices impact more than just her direct descendants: she is also liable for the future of humanity itself on this microbial planet. In

[73] Dietert's own popular-press microbiome book is highly ableist; what's unstated here is elsewhere clarified as a determination to see neurodivergence as biologically deranged, fixable by microbiome intervention.

the conclusion of *Microbirth*, the net-wielding children reappear alongside the multigenerational tea party as a series of researchers offer their final thoughts on the problem of CSD. Among them is Dominguez-Bello, who tells viewers: "It's a global problem. It's not an American problem, it's not a European problem, it's not a Japanese problem, it's not a Chinese problem. It's a humanity problem. It is." Her point is echoed widely. Generational inheritance and familial connection hangs in the balance with each act of birth. In the film's final moment, a researcher asks as the screen cuts to dark, "how do we know that we're not altering the course of humanity?"

A half century earlier, *2001: A Space Odyssey* had imagined an arc of civilizational progress, of evolution to and beyond the human as driven by technological achievement. But this trajectory comes as a cost, with nuclear weapons cast as the endpoint of that achievement; as Sofia has written, "evolution climaxes in the arms race" (49). The film's reincarnated Bowman—its ethereal star-child, motherless and timeless—therefore signifies a deeply ambivalent journey Earthside in which human progress and human survival are at odds (Figure 26). The researchers interviewed in *Microbirth* are likewise crafting a civilizational narrative that situates Cesarean birth as participating in—and driving forward—a global microbiomic disaster as wrought by birth interventions that put humanity at risk. In presenting humans' relationship to microbes as an ancient entity entwined with the planet itself, they identify Cesarean delivery as a problem of modernity deeply rooted in humans' pursuit of ecological dominion. Here, evolution climaxes not in nuclear weapons but in scalpels and forceps, in allergies and obesity, in severed mother-baby bonds. Yet it would seem that this crisis is no less severe.

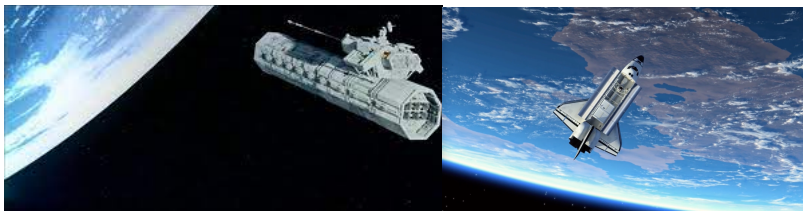

Figure 26. Evolution climaxes in the arms race (2001) and spaceflight (Microbirth), and in both cases we are civilizationally ill.

In *Microbirth*, obstetric intervention is aligned with an broader arc of technological progress. In an echo of *2001's* opening sequence, the film opens with a montage that narrates a story of steady progress, jumping between images of Stonehenge, da Vinci's Vitruvian Man, city skylines, and at last a series of spacecraft in flight (Figure 7). The narrator intones:

> We have looked to the stars. We have searched our souls … We connect, communicate, invent, and create. We are able to cure, to treat, to extend life, even to create life. We have built cities that touch the sky, we have flown among the clouds, and traveled far beyond… Now we have surely arrived at the golden age of technology. Never before have we appeared to be stronger, more powerful, and more in control. Why is it, then, that at this moment in time our species has never been sicker?

Health is inversely correlated with human progress: the more we achieve, the further we stray from the primordial world and our microbiomic heritage, the sicker we get.

Microbirth captures the precarity of this technological pinnacle through the tropes of outbreak fiction, foretelling a global public health crisis unfolding on the surface below the serenely floating spacecraft. Borrowing the catastrophic register of climate change discourse and of microbiome writing more generally, it projects a looming crisis that will extend far beyond the impact of individual births.[74] "If we continue on the same path," the narrator says, "it's conceivable that our

[74] On catastrophe discourse in contemporary microbiomics more generally, see Brigitte Nerlich.

actions could actually be accelerating… toward the disaster scenario" anticipated at the outset of the film, of pandemic-scale crises and the resulting threats to national security, healthcare, and the economy. That urgency is captured in the film's reliance on the visual tropes of outbreak narratives: glowing green viral particles, heroic scientist figures, maps of flight paths, sirens, and a sense of imminent crisis. The threats of viral epidemic and Cesarean epidemic converge, suggesting that both arise from an interconnected modern world in which people have lost sight of their relationship to microscopic life.

Microbirth summons a particularly frenzied panic at the idea of a global epidemic of Cesarean birth, but the scientific texts share its basic narrative framework, telling their own tale of humanity imperiled by the arc of technological progress. This version essentially restages the germfree apocalypse tropes so often recruited in microbiome writing (Chapter 2) in suggesting that modern childbirth practices are materially reshaping the geographies and microbial communities of the germy planet on which we evolved. Cesarean births and their damages belong to a wholesale disregard for the natural world that has unwittingly destroyed the integrity of the human microbiome. The microbiome itself is under threat as humanity careens toward a germfree future of its own making.

In the civilizational narrative outlined in Dominguez-Bello's texts, the modern philosophy of antibiosis has systematically reduced the balance and diversity of microorganisms with which we live. In the scientific texts, that accusation takes shape as a distancing from the "ancestral" microbiota as it evolved in time. As others have noted, microbiome research has often revered the microbiomes of indigenous peoples, who are set forth as embodying "whole" state of the human-associated microflora.[75] The implication is that the antiseptic habits of modern life are systematically distancing

[75] On racialization in microbiome research, see (Benezra) and (Nieves Delgado and Baedke).

Westerners from this evolutionary past. Since at least 2011, Dominguez-Bello has been involved in efforts to quantify discrepancies between indigenous and "modern" human microbiomes, seeking to contextualize modern birth interventions within a global pattern of "urbanization," "modernization," and/or "industrialization." Much as the birth canal affords a glimpse into the ancestral microbiome so long as it remains unperturbed by interventions, indigenous people are suggested to possess the microbiome in its purest form. In both cases, it is threatened by the changes associated with the modern world.

For instance, in a figure included in the 2018 *Science* commentary, Dominguez-Bello and coauthors characteristically align human history with a progressive geographical alteration from the landscape, from "jungle, savanna" to "rural" and then "urban" habitats (Figure 27). These changes are indicated by the forward arrow labeled "time," which traces a narrative unfolding of global progress. As Dominguez-Bello and collaborators write elsewhere, these geographic transitions bring with them not only altered landscapes but also changes to how humans live within them, to "housing, urban plan, human density, home architecture, technologic isolation of houses from the environment, ventilation…" (2019, *Gut*, 68).

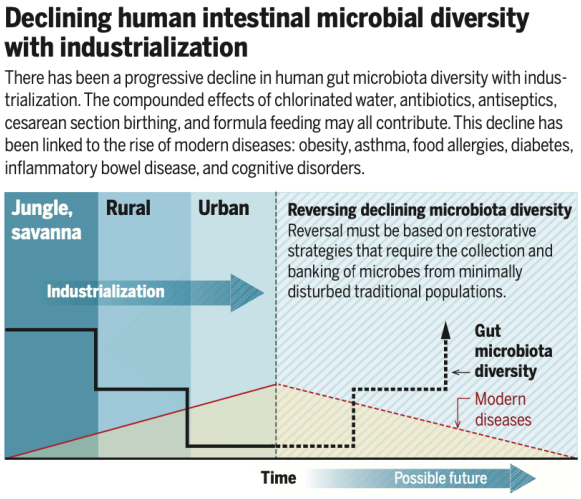

Figure 27. Dominguez-Bello et al, Figure 1 in "Preserving Microbial Diversity" (2018).

And as in the fictional precursors on which they draw, the changes defining modern life threaten our own survival. As the 2018 figure states, "there has been a progressive decline in human gut microbiota diversity," a trend illustrated in the stepwise progression of the line labeled "gut microbiota diversity," alongside a peak in modern diseases. They continue, "the compounded effects of chlorinated water, antibiotics, antiseptics, cesarean section birthing, and formula feeding may all contribute." It is a point reiterated widely across the corpus: as the world becomes increasingly urban, and as humanity inches ever further away from the untouched ancestral microbiome, people become sicker.

In emphasizing discrepancies between Western and indigenous microbiomes, Dominguez-Bello et al. again summon the prospect of a germfree world in progress. As the figure's arrow of industrialization moves forward, gut microbiota diversity creeps closer to zero, a trend that can only be reversed (they suggest) by taking actions to "revers[e] declining microbiota diversity." Otherwise, people advance ever closer to germfree catastrophe. In a move common across popular science writing on the microbiome, "Preserving Microbial Diversity" elides diversity loss and germfreeness: the threat is not that the species in our bodies change, but that they become extinguished altogether. In the text of the article, the authors overwhelmingly project an antiseptic future as the culmination of industrialization. They write that key microbial species are not diminished but rather "disappearing" or experiencing "losses" and "extinctions." Here as elsewhere, birth interventions and modern practices are driving a disappearance—not of microbial diversity, but of the microbiome itself. And time is running short. They write, "it is paramount that we expand the efforts to capture and preserve the human microbiota while it still exists" (34). Time is critical, for the human microbiome as an entity stands on the brink of extinction; restoration strategies "must begin before it is too late" (34).

Whether through a dysbiotic pandemic as in *Microbirth* or through a coming germfree apocalypse in "Preserving Microbial Diversity," birth stands poised to forestall the looming catastrophe. Each act of CSD violates an individual child's welfare as well as human health on a global scale. As the narrator in *Microbirth* insists over scenes of pandemic crisis, "it all begins with birth." Priscilla Wald has written that outbreak narratives gain their moral force through myth, by framing modern illnesses as arising from transgression as modern humans collide with hidden, natural spaces; illness is therefore the cost of tinkering with nature, a sin of contemporary life. While the narrative structure of Dominguez-Bello's corpus is more closely aligned with germfree fiction than outbreak narratives, its texts draw the same moral imperative from the elision of illness with planetary history. CSD signifies a violation of nature in the context of a world blind to microscopic life. As Howes-Mischel has observed in her analysis of *Microbirth*, "when conditions of modernity are framed as problems 'seeded by' women's bodily environments, narratives about microbiome research seed a future that itself reproduces pernicious ideas about maternal responsibility as (literally) bearing the weight of the world" (118).

5. Conclusion: To See(d) a World in a Microbiome

If birth is the problem, then birth is also the answer. Consistent with their precursors in germfree fiction, Dominguez-Bello and her collaborators suggest that planetary and social reparations for the harms of modern life can only be made by rejecting (obstetric) technology and returning to a peaceful coexistence with the microbes of our world—in this case, through vaginal birth. The intergenerational handoff of the microbiota by a laboring mother is thus an act of redemption for a broken world, a rebellious performance of microbiome-colonization. By granting direct access to an ancestral past in which humans were once whole, the vaginal microbiota becomes

the antidote for a civilization lurching toward germfree catastrophe, promising to restore what is being lost.

That promise crystallizes in the prospect of vaginal seeding, a procedure developed by Dominguez-Bello to transfer the vaginal microbiota to CSD infants shortly after birth. In this protocol, first reported in a study published in *Nature Medicine* in 2016, mothers delivering by scheduled C-section incubate gauze in their vaginas in the hour preceding delivery, during which it absorbs resident microbes; upon birth, researchers transfer those microbes to the newborn by swabbing them with the gauze (Dominguez-Bello et al. 2016, "Partial Restoration"). Vaginal seeding was conceived as a means of reversing the microbiome losses of CSD, and indeed the pilot study found swabbed babies to exhibit an phenotype intermediate between VD and CSD. Dominguez-Bello et al. deem this pattern a "partial restoration" of the maternal microflora that would otherwise be lost in CSD. Yet seeding is more than a reversal of microbiome phenotypes. Presented as a "restoration," it alludes to recovery for more than just the infant in question. The maternal microflora, however they are transferred, carry the possibility of seeding a better future that the mother must take care to bring about.

And she is saving all of us. Across this corpus and the adjacent popular science discourse, the microbiome functions widely as tool of salvation. For instance, the image in Figure 28 below is drawn from *My Natural Baby Birth* (originator of the "choice to rob" quote above). "Are you seeding baby's microbiome?" it asks. "It will affect their entire future." In this case the "seeding" refers to vaginal delivery more than Dominguez-Bello's restoration strategy. But regardless, the image captures how the duty to seed is a duty not just to one's child but also to the world. In it, a globe appears nestled between two leaves—or rather, appears to be crowning between two labial folds. The baby is the world; in seeding her child, a mother alters the future for us all.

Figure 28. Lead image for Prince's post at MyNaturalBabyBirth.

The hope of saving the world through the microbiome surfaces most dramatically in "Preserving Microbial Diversity." The article's projection of an imminent germfree future is answered in a proposal to mitigate the damages of that future by biobanking microbiomes. The authors propose the construction of an underground storage facility to be "a global repository of human-associated microbes… similar in principle to the inspiring example of the Seed Vault established in the permafrost of Svalbard Island in Norway to preserve the natural biodiversity of plants" (34). But while the actual proposal is designed as a "backup" to safeguard existing research samples in collections worldwide, the narrative framework of the article is of regeneration in the wake of the coming apocalypse. The image included in the proposal's external website encapsulates the threat: antibiotic winter, desolation, a post-apocalyptic world (Figure 29) (Microbiota Vault).

Figure 29. Microbiota Vault's homepage. This is not Svalbard.

The article proposes the collection of gut microbiomes rather than vaginal samples, per se. Yet it shares with obstetric microbiology discourse the presentation of ancestral microbiomes as the salvation of humanity after the inevitable catastrophe. That stance is underscored in popular science's reporting on the proposal, in which the vault is described as a "Noah's ark" and a "doomsday vault." The seeds of the human microbiome hold the promise of reversing the damages humans have wrought on the microorganisms of this world.

In these calls for vaginal birth (or reparations by means of vaginal seeding) and gut microbiome storage, the microbial mother disappears from view once more. Though this collection of texts and interviews purports to be empowering in its celebration of what "mom knows best" and its potential to shape the lifecourse of both baby and world, in the end it reduces a mother to her reproductive function. "Preserving Microbial Diversity" concludes, "we owe future generations the microbes that colonized our ancestors for at least 200,000 years of human evolution" (34). Like the indigenous people whose microbiome samples are to reside underground to guard against antimicrobial apocalypse, the microbial mother is revered for her microbiota—and these she must attend to before herself. Failure to do so is the mark of a monstrous mother who neglects her child, future generations, and the world in depriving them of the birthright to which they are entitled. Mothers are erased, bodily and intellectually subsumed into the teeming life of their own vaginas and of the planet. Passage out of the gravid uterus is therefore the site of a future that will save us all. Push your baby out, and save the world.

Works Cited

Ackerman, Jennifer. "The Ultimate Social Network." *Scientific American*, vol. 306, no. 6, June 2012.

American College of Obstetricians and Gynecologists. "Committee Opinion No. 725: Vaginal Seeding." *Obstetrics & Gynecology*, vol. 130, no. 5, Nov. 2017, pp. e274–78.

Ayala, Saray, and Lauren Freeman. "The Placental Microbiome: A New Site for Policing Women's Bodies." *International Journal of Feminist Approaches to Bioethics*, vol. 9, no. 1, Spring 2016, pp. 121–48.

Benezra, Amber. "Race in the Microbiome." *Science, Technology, & Human Values*, vol. 45, no. 5, Sept. 2020, pp. 877–902.

Berlant, Lauren. "America, 'Fat,' the Fetus." *Boundary 2*, vol. 21, no. 3, 1994, pp. 145–95.

Blaser, Martin J., and Maria G. Dominguez-Bello. "The Human Microbiome before Birth." *Cell Host & Microbe*, vol. 20, Nov. 2016, pp. 558–60.

Breslau. "Ueber entstehung und bedeutung der darmgase bei neugeborenen kindern." *Monatschr. f. Geburtsh. u. Frauenkr.*, vol. 28, no. 1, 1866.

Cernohous, Sarica. "How's Your Psycho-Biome?" *Naturally Living Today*, https://naturallylivingtoday.com/hows-your-psycho-biome/. Accessed 1 July 2021.

Cohen, Ed. A Body Worth Defending: Immunity, Biopolitics, and the Apotheosis of the Modern Body. Duke University Press, 2009.

Combellick, Joan L., et al. "Differences in the Fecal Microbiota of Neonates Born at Home or in the Hospital." *Scientific Reports*, vol. 8, no. 1, Dec. 2018, p. 15660.

Crichton, Michael. *The Andromeda Strain*. Vintage Books, 2012.

Dominguez-Bello, Maria G., et al. "Delivery Mode Shapes the Acquisition and Structure of the Initial Microbiota across Multiple Body Habitats in Newborns." *PNAS*, vol. 107, no. 26, June 2010, pp. 11971–75.

---. "Development of the Human Gastrointestinal Microbiota and Insights From High-Throughput Sequencing." *Gastroenterology*, vol. 140, no. 6, May 2011, pp. 1713–19.

---. *The Human Microbiome in an Age of Disruptive Change*. Storer Lectureship in Life Sciences, UC Davis.

---. "Partial Restoration of the Microbiota of Cesarean-Born Infants via Vaginal Microbial Transfer." *Nature Medicine*, vol. 22, no. 3, Mar. 2016, pp. 250–53.

---. "Preserving Microbial Diversity." *Science*, vol. 362, no. 6410, Oct. 2018, pp. 33–34.

---. "Role of the Microbiome in Human Development." *Gut*, vol. 68, no. 6, June 2019, pp. 1108–14.

Dominguez-Bello, Maria Gloria, and Martin J. Blaser. "The Human Microbiota as a Marker for Migrations of Individuals and Populations." *Annual Review of Anthropology*, vol. 40, no. 1, Oct. 2011, pp. 451–74.

Escherich, T. "The Intestinal Bacteria of the Neonate and Breast-Fed Infant." *Clinical Infectious Diseases*, vol. 10, no. 6, Nov. 1988, pp. 1220–25.

Funkhouser, Lisa F., and Seth R. Bordenstein. "Mom Knows Best: The Universality of Maternal Microbial Transmission." *PLOS Biology*, vol. 11, no. 8, Aug. 2013.

Gilbert, Scott F., and Rebecca Howes-Mischel. "'Show Me Your Original Face Before You Were Born': The Convergence of Public Fetuses and Sacred DNA." *History and Philosophy of the Life Sciences*, vol. 26, no. 3/4, 2004, pp. 377–94.

Harman, Toni. "Shortchanging a Baby's Microbiome." *Scientific American*, 14 Feb. 2017, https://blogs.scientificamerican.com/guest-blog/shortchanging-a-babys-microbiome/.

Harman, Toni, and Alex Wakeford. *Microbirth*. 2014.

Holland, Jennifer L. *Tiny You: A Western History of the Anti-Abortion Movement*. University of California Press, 2020.

Hopkins, Nick, et al. "Visualising Abortion: Emotion Discourse and Fetal Imagery in a Contemporary Abortion Debate." *Social Science & Medicine*, vol. 61, no. 2, July 2005, pp. 393–403.

Houf, Jessica R. "The Microbial Mother Meets the Independent Organ: Cultural Discourses of Reproductive Microbiomes." *Journal of Medical Humanities*, Aug. 2017.

Howes-Mischel, Rebecca. "Seeding the Future: Maternal Microbiome as Maternal Embodiment." *Bearing the Weight of the World: Exploring Maternal Embodiment*, Demeter Press, 2018, pp. 101–22.

Kubrick, Stanley. *2001: A Space Odyssey*. Metro-Goldwyn-Mayer, 1968.

Lorimer, Jamie. "Gut Buddies: Multispecies Studies and the Microbiome." *Environmental Humanities*, vol. 8, no. 1, May 2016, pp. 57–76.

McKenna, Maryn. *MRSA: The Drug-Resistant "Superbug" That Won't Die*. 23 Mar. 2010, https://www.npr.org/2010/03/23/124999740/mrsa-the-drug-resistant-superbug-that-wont-die.

Meghie, Stella. *Everything, Everything*. Metro-Goldwyn-Mayer and Alloy Entertainment;, 2017.

Microbiota Vault. *A Vault for Humanity*. http://www.microbiotavault.org/. Accessed 1 July 2021.

Morgan, Lynn M., and Meredith Wilson Michaels, editors. *Fetal Subjects, Feminist Positions*. University of Pennsylvania Press, 1999.

Mueller, Noel T., et al. "The Infant Microbiome Development: Mom Matters." *Trends in Molecular Medicine*, vol. 21, no. 2, Feb. 2015, pp. 109–17.

Nerlich, Brigitte. "'The Post-Antibiotic Apocalypse' and the 'War on Superbugs': Catastrophe Discourse in Microbiology, Its Rhetorical Form and Political Function." *Public Understanding of Science*, vol. 18, no. 5, 2009, pp. 574–90.

Nieves Delgado, Abigail, and Jan Baedke. "Does the Human Microbiome Tell Us Something about Race?" *Humanities and Social Sciences Communications*, vol. 8, no. 1, Dec. 2021, p. 97.

Park, Katharine. Secrets of Women: Gender, Generation, and the Origins of Human Dissection. Zone Books ; Distributed by the MIT Press, 2006.

Perez-Muñoz, Maria Elisa, and et al. "A Critical Assessment of the 'Sterile Womb' and 'in Utero Colonization' Hypotheses: Implications for Research on the Pioneer Infant Microbiome." *Microbiome*, vol. 5, no. 48, 2017.

Petchesky, Rosalind Pollack. "Fetal Images: The Power of Visual Culture in the Politics of Reproduction." *Feminist Studies*, vol. 13, no. 2, 1987, p. 263.

Prince, Sarah. "Are You Seeding Baby's Microbiome? It Will Affect Their Entire Future." *My Natural Baby Birth*, https://mynaturalbabybirth.com/are-you-seeding-babys-microbiome-it-will-affect-their-entire-future.

Rosebury, Theodor. *Life on Man*. The Viking Press, 1969.

---. Microbes Indigenous to Man. McGraw-Hill, 1962.

Rudavsky, Shari. "C-Section 'seeding' Freaks out New Mothers." *USA Today*, 5 Apr. 2016, https://www.usatoday.com/story/news/nation-now/2016/04/05/c-section-seeding-freaks-out-new-mothers/82674066/.

Sharp, Gemma C., et al. "It's the Mother!: How Assumptions about the Causal Primacy of Maternal Effects Influence Research on the Developmental Origins of Health and Disease." *Social Science & Medicine*, vol. 213, 2018, pp. 20–27.

Sheldon, Rebekah. *The Child to Come: Life after the Human Catastrophe*. University of Minnesota Press, 2016.

Sofia, Zoë. "Exterminating Fetuses: Abortion, Disarmament, and the Sexo-Semiotics of Extraterrestrialism." *Diacritics*, vol. 14, no. 2, Summer 1984, pp. 47–59.

Stein, Rob. "Doctors Test Bacterial Smear After Cesarean Sections To Bolster Babies' Microbiomes." *NPR*, 30 Oct. 2018, https://www.npr.org/sections/health-shots/2018/10/30/658254175/doctors-test-bacterial-smear-after-cesarean-sections-to-bolster-babies-microbiom.

Stinson, Lisa F., et al. "A Critical Review of the Bacterial Baptism Hypothesis and the Impact of Cesarean Delivery on the Infant Microbiome." *Frontiers in Medicine*, vol. 5, May 2019.

Stinson, Lisa F., and et al. "Planting the Seed: Origins, Composition, and Postnatal Health Significance of the Fetal Gastrointestinal Microbiota." *Critical Reviews in Microbiology*, vol. 43, no. 3, 2017, pp. 352–69.

Takeshita, Chikako. "From Mother/Fetus to Holobiont(s): A Material Feminist Ontology of the Pregnant Body." *Catalyst: Feminism, Theory, Technoscience*, vol. 3, no. 1, 2017, pp. 1–28.

Tissier, Henri. Recherches sur la flore intestinale des nourrissons (état normal et pathologique). G. Carre and C. Naud, 1900.

Wald, Priscilla. Contagious: Cultures, Carriers, and the Outbreak Narrative. Duke University Press, 2008.

Yong, Ed. "Baby's First Bacteria Depend on Route of Delivery." *Not Exactly Rocket Science*, 23 June 2010, https://www.nationalgeographic.com/science/article/babys-first-bacteria-depend-on-route-of-delivery.

---. "Breastfeeding the Microbiome." *The New Yorker*, July 2016, https://www.newyorker.com/tech/annals-of-technology/breast-feeding-the-microbiome.

---. I Contain Multitudes: The Microbes Within Us and a Grander View of Life. Harper Collins, 2016.

Zimmer, Carl. "How Microbes Defend and Define Us." *The New York Times*, 12 July 2010, https://www.nytimes.com/2010/07/13/science/13micro.html.

Talking with Microbes

If you listen carefully, you'll find that your microbes are talking to you. A stream of constant chatter, a string of messages, travels from your gut to your brain. And ever so delicately, the bacteria that constitute your gut microbiome are telling you that they really need a pizza.

This suggestion is made in the 2017 popular science book *The Psychobiotic Revolution,* by scientist authors John F. Cryan and Ted Dinan in collaboration with science journalist Scott C. Anderson. The book centers on the gut-brain axis, through which these two organs are linked by molecular signaling across the vagus nerve connecting them, coordinating hunger and other phenomena. But where research in this area has traditionally centered only on human cells, these authors advocate for expanding the view to encompass the microbiota, which participate in the communicative circuit through the secretion of neurotransmitters. They characterize this gut-brain-microbiome axis (GBMA) by adopting a recurring trope of microbial communication. In a section titled "How Microbes Order Pizza," they write:

> Your microbiota has needs and … has learned how to tell you about them. When you wake up craving a doughnut, where do you think that idea came from? Your cravings are often just committee memos sent up from your gut microbes. They contain a complete list of the carbs, sugars, and fats they are looking for. (Anderson et al. 54)

These bacteria are both hungry and chatty, friendly and demanding. Bacterial pizza-ordering is a graphical exercise, taking shape as memos or lists that *tell* the host about their desires. Brain and gut, together, are poised to listen.

At first blush, it might appear that the human recipients of these committee memos are yet again rendered subservient to their microbes, compelled to reach for pizza and doughnuts in order to feed the microbes controlling their brains. The suggestion is, after all, consistent with the early

years of microbiome discourse in the U.S., in which microbiomes have consistently been in control of the humans possessing them. Is this depiction of hungry, communicative bacteria simply another means of suggesting that our microbes make us who we are and that we must defer to their whims?

The Psychobiotic Revolution certainly exemplifies the microbiome writing tradition I have been analyzing. Like its precursors, it takes the newly recognized roles of microbes to be crucial in restoring an ideal, healthy human: a site of intervention in the name of better health. The authors are also fluent in the tropes of the genre, from bubble boys to germfree mice. But this book marks a shift: the authors take a different approach to how the microbiome might be lived with. Specifically, they advocate for the consumption of particular "psychobiotics"—foods and pharmaceutical agents that can shift our neurobiology by modifying the bacterial populations in the gut so as to attain improved health, mood, or weight. Unlike previous conceptions of microbial-human relationships, here humans are active participants. Where microbiomics and gut-brain research collide, a serious reckoning with how we interact with our internal symbionts is underway.

The question of how to intentionally shape one's microbiome though psychobiotics belongs to a broader material shift in microbiome discourse spanning approximately the past five years. With the conclusion of the Human Microbiome Project and other sequencing initiatives, microbiomics has moved into a functional genomics phase in which the question is not so much "who's here?" as "now what?"[76] Attention increasingly turns toward solutions and therapies aimed at refining the microbiota so as to prevent disease and achieve health. This shift also responds to the loss of self so

[76] Microbiome research in the U.S. can be grouped into three general phases. First came early efforts to catalogue microbial life on the human body, as typified in the first phase of the Human Microbiome Project. The HMP's second phase, the Integrative HMP, and similar projects conducted longitudinal studies of microbial changes associated with disease. The third and current stage—the "what's next?" stage—is more open-ended, seeking translational interventions. The discourse of psychobiotics characterized in this chapter falls primarily into the third of these categories. Fasano and Flaherty, in *Gut Feelings* (2021), undertake a broad overview of microbiome history with particular emphasis on targeted microbiota manipulation. For scientific commentaries articulating the shift toward functional metagenomics, see (Proctor) and ("After the Integrative Human Microbiome Project"), two 2019 calls for multidisciplinary collaboration as microbiome research addresses ever more dynamic and mutable populations.

commonly articulated in the early microbiome years. The microbiome is no longer an ancestral object that supersedes the individual, determined by birth delivery mode and by the degree to which a society adheres to "ancestral" practices like fermentation. Instead, functional metagenomics asks how the microbiota might manifest, and be modified, at the level of an individual. In science and in popular microbiome discourse, the early and dominant suggestion that the microbiome is imperiled by modernity is growing less incisive. We are, perhaps, at this moment fatigued of our antiseptic imaginations, the constant turns to bubble kids and antibiotic apocalypse, and the overshadowing of human agency in deference to our germs. Is it possible that the modern microbiome is not disappearing but rather, awaiting modification?

This shift has been palpable, particularly as GBMA research began consolidating as a research discipline. By 2016, as Bencard and Whiteley have observed, the microbiome-brain connection appeared as "a 'hot topic' and an interesting case study of a complex, unsettled research field with potentially profound implications for both medicine and culture" (1). In popular science, authors have sought to convey possibilities of this research through metaphors of bacterial communication. *The Psychobiotic Revolution* encapsulates this trend in sustained form. Gut microbes, it turns out, do not merely draft up committee memos demanding pizza; they also *talk*. The authors write, "bacteria can talk to you. The intricacies of this conversation make the Internet look quaint. There are 4 billion Internet users, but you have 10 *trillion* bacteria in your gut alone that are all sending messages to each other—and to you" (53). In its intricate conversations, the web of microbial communication within exceeds the vastness of human communications. Notably, psychobiotic intervention is also framed as a communicative act. The authors describe a bidirectional conversation in which "your brain can talk back to your gut through these same channels" (53). In this vision of human-microbial interchange, the brain is not merely subjected to

the whims of hungry microbes. Psychobiotic consumption is a communicative act that encodes meaning for bacterial recipients. For instance, Anderson et al. write that it is important to embark on the project of "learning the language of your microbes." Here and across GBMA discourse, human-microbial interactions are illustrated as a meeting of the minds in which both sides collaborate as conversational partners.

As this chapter will show, it is a conceit decades in the making. Scientists have long relied on speech and language metaphors to describe the signaling pathways through which bacteria coordinate behavioral changes amongst themselves at the population level. So too have science fiction authors, who have often attempted to transform microbes into characters by granting them linguistic capabilities with which to converse with humans. GBMA discourse directly inherits these frameworks, but also builds upon them. Bacteria are now chatting not only amongst themselves but also, materially, with their human hosts through the circulation of meaning-laden signaling molecules. In populating the human gut with linguistic, social individuals, scientists and popular science writers are manifesting the science fictional dream of speaking together in conversations that transcend differences of scale and species.

Microbes have been made to "talk" before in more literal ways that blur the boundary between human and laboratory organism. Sophia Roosth, for instance, describes the amplification of yeast vibrations to render a sound that scientists have referred to as "screaming"; she writes that "interpreting cellular noise as screams forces attention on the shared cellularity of humans and yeast… Endowing yeast with agency by calling upon an anthropocentric model of subjectivity, scientists transform objects of scientific research into cellular subjects" (339).[77] GBMA discourse

[77] Other amplification approaches include Tyler Fox's *Fermentum*, a bioart project which amplifies the sounds of fermenting sauerkraut and kimchi in order to "appreciate the operation, or processes, of individuation" (Fox); as well as Anna Dumitriu's project "Communicating Bacteria," which visualizes QS in real-time, via amplification and color tagging on a fabric surface.

similarly forges a shared subjectivity between bacteria and people, but in a more expansive imaginative mode. Speech—conversation—implies an apprehension of the other, a recognition of shared intellect. In the context of the research transition between genome sequencing and functional genomics, the idea of microbial speech emerges as a hopeful alternative to the theme of modern life's antibiotic devastations. Talking with our microbes resists the slide into antibiosis by cultivating an ethos of care and collaboration.

This chapter traces the surfacing of the microbiome-brain speech conceit from within a deeper metaphorical and narrative history. I show how professional scientific writing has long described bacterial cell-to-cell signaling using comparisons to human society, moving successively through metaphors of governance, language, and sociality in a progressive humanization of bacterial life.[78] GBMA metaphors culminate this tradition in uniting microbial and human entities as conversational partners. The chapter also shows how the arc toward conceptualizing bacteria as conversational beings has been both anticipated and reinforced in science fiction. While numerous fiction authors over the history of microbiology have given voice to microbes as a means of drawing them into the drama of human plots, I focus below on three particularly sustained engagements with talking microbes in stories by Greg Bear, John Russell Fearn, and Joan Slonczewski. These illuminate the possibilities and constraints of science's various metaphorical frameworks, revealing how early governance and sociality comparisons had confined microbes to antagonistic roles rendering coexistence impossible. In contrast, GBMA discourse transcends the narrative limitations

[78] There is a substantial body of work in STS concerning the role of metaphor in shaping both professional and popular conceptions of scientific work as well as influencing the trajectory of scientific research itself, including Donna Haraway, Gillian Beer, and many others. Metaphors like those I discuss in this chapter also reflect cultural beliefs and assumptions; as Brendon Larson notes, "when scientists use a metaphor, they are endorsing particular values" (195) – in this case, about the narrowness of the traditional human-centered perspective in microbiology. Of particular interest to my analysis of language and political metaphors are work by Richard Doyle and Lily E. Kay on language metaphors in molecular biology, which forms a background to QS's description of the transduction of meaning across space as encoded in signifying molecular messages. Also relevant is Emily Martin's and Donna Haraway's discussion of immune system metaphors as encoding values of gender and political economy.

of earlier conceptions of bacterial capabilities. In merging these fictional and scientific traditions, GBMA researchers articulate a vision of living with microbes collaboratively, with both human and microbial entities coming together as conversational partners and equals.

1. History of Quorum Sensing

Bacteria began to find their voice in the late 1960s, when a trio of researchers at Harvard University and the Marine Biological Laboratory at Woods Hole noticed that their bacterial cultures were exhibiting a strange glowing pattern. It wasn't the fact that they glowed—this strain of marine bacteria, *Photobacterium fischeri,*[79] is naturally bioluminescent—but that their light and growth patterns were out of sync. Rather than demonstrating a steady increase in light intensity as the cultures grew denser, these cells remained dark for a prolonged period before rapidly switching on the lights, seemingly in response to crossing a density threshold (Figure 30) (Nealson et al.).

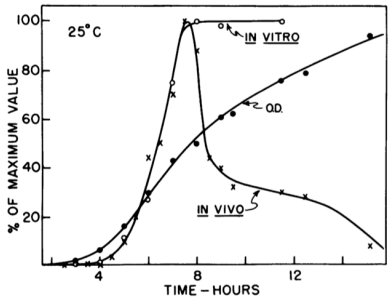

FIG. 2. *Experiment of Fig. 1 plotted on a linear scale, better illustrating the "pulse" nature of the luciferase synthesis and in vivo luminescence. The ordinate values were all normalized to the maximum and plotted as the per cent of that value.*

Figure 30. Nealson, Platt, and Hastings 1970. Note the different increases between bacterial density (central line, "O.D.") and light production (spiked line, "in vitro").

[79] Now classified as *Aliivibrio fischeri.*

Nealson, Platt, and Hastings concluded that this pattern was due to transcriptional regulation of the luciferase (glow-producing) gene, brought about by conditioning of the growth medium by some unidentified molecular factor (313). Observing that this factor was produced by the growing cells themselves, rather than by any external intervention, they termed the phenomenon "autoinduction" (313). Though unable to identify the function of such a system, they suggested that the existence of this luciferase control mechanism must indicate that "the bioluminescence of these bacteria has some very special biological function" (321) leading it to persist despite being an energetically costly cellular behavior.

During the 1970s, these and other researchers began to suspect that bacterial cells used autoinduction as a means of environmental sensing, triggering bioluminescence only when high population density indicated energetically favorable conditions. Nealson hazarded a guess as to the ecological significance of this possibility in 1977, writing that "one is tempted to hypothesize that the bacteria can use bioluminescence to some advantage when conditions are favorable, and that they can repress it when conditions are dilute and limiting" (78). He suggested that this phenomenon might indicate a survival strategy for bacteria existing in association with host organisms such as luminous fish: "When associated they will be luminous and 'donate' the luminescence to their associate. When free living (unassociated) they will be dark, conserving energy and possibly increasing their survival time in the limiting oceanic environment until another substrate (host) for association is acquired" (78).

The economic logic of such a hypothesis may seem straightforward, but in fact was quite contentious at the time. The idea that bacteria might be capable of detecting their own population density, lighting up after recognizing themselves to be sufficiently numerous, was unexpected and

unsettling. Autoinduction seemed to work against the standard view that bacteria were self-contained and mechanistic, concerned only with reproduction.

Later researchers have frequently identified this hypothesis as a challenge to the standard view, expressed by molecular biologist Francois Jacob, that a bacterium is but a little machine, "a miniaturized chemical factory" but with even less purpose: "A bacterium continually strives to produce two bacteria. This seems to be its one project, its sole ambition… The factory produces; the cell reproduces" (271). Microbiologists Dunny and Winans, for instance, have argued that Jacob's assertions typify "the paradigm of the asocial existence of the bacterial cell," which has been "a major intellectual force driving research in modern microbiology" but which must be left behind to accommodate new information about bacterial interactivity (1).

The idea that autoinduction and bacterial communication represented a paradigm shift is frequent in the literature. In a retrospective piece some 20 years later, for instance, Nealson recalls his group's difficulty in having this model accepted. A diagram attempting to explain the process, he says, was repeatedly removed from submitted manuscripts on the grounds that "bacteria just don't do this" ("Early Observations Defining Quorum-Dependent Gene Expression"). He attributes that refrain of rejections to "a reluctance to accept the notion of intercellular communication by bacteria. The concept that bacteria might put something into the growth medium that could act in some form of intercellular communication was not ready for acceptance" (p. 285).

Over the subsequent decades, however, autoinduction found steady support as scientists gradually elucidated its underlying genetic mechanisms.[80] The LuxI/LuxR system, underlying *P. fischeri*'s bioluminescence, remains the best characterized. In this system, visually represented in Figure 31, below, a cell constitutively secretes into its environment small diffusible molecules—

[80] E.g., (Engebrecht and Silverman).

autoinducers—produced by the LuxI protein (shown as black triangles in the diagram below). At the same time, the cell is also continually absorbing environmental autoinducers, which bind to the LuxR protein and, after reaching a certain autoinducer concentration, activate the protein to increase transcription of the associated genes, thereby triggering autoinducer-linked behaviors to appear.

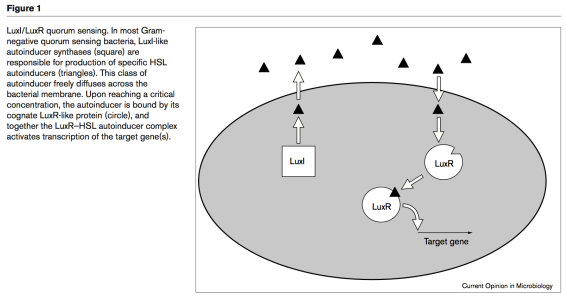

Figure 31. Basic autoinduction schematic for the LuxI/LuxR system, reproduced from (Bassler 1999).

Moreover, genetic sequencing has revealed that autoinduction is strongly conserved across bacterial species, occurring in multiple distinct classes, though all share the same basic biology of the system described above. Autoinduction is now understood to mediate not only bioluminescence but also genetic processes such as competence (environmental DNA uptake) and conjugation (exchange of DNA between cells), virulence factors in disease-causing organisms, developmental processes such as spore production and biofilm formation, and more.

Yet if autoinduction as a molecular process is no longer controversial, it still manages to surprise, challenging readers with the prospect of interactive bacteria. The jokes and far-fetched metaphors commonly used in scientific literature reveal that bacterial communication continues to elicit the same impulse Nealson once attributed to his critics: that "bacteria just don't do this." Below, I trace how scientists have recruited lively metaphors for autoinduction to define a microbial sociality that upends preconceptions of how humans and microbes relate.

The original term, *autoinduction*, carries a mechanistic connotation that implies a certain isolation in locating the signaling organism as both originator and (potential) recipient of its own signal: it induces itself.[81] In contrast, the more recent shift to speech, language, and sociality metaphors begin from the premise of a group identity. In defining bacteria first as political aggregates, and then linguistic, social beings, scientific metaphors have set them on a trajectory toward ever greater interactivity and individuality. This arc culminates in the contemporary imagination of lively conversations between the microbiome and the human brain. In other words, bacteria have gradually found their voice, increasingly becoming a part of their own conversations—and drawing ever closer to the humans leaning in to listen.

2. Metaphors of Quorum Sensing: Bacterial Governance

Autoinduction got a new name in 1994, one that likened it to human communication—more particularly, human governance—when three researchers published a landmark review article in *Journal of Bacteriology* proposing to consolidate the field under revised terminology. Titled "Quorum Sensing in Bacteria: the LuxR-LuxI Family of Cell Density-Responsive Transcriptional Regulators," it announced a new prominence for the field as well as a rhetorical redefinition of autoinduction, now referred to as "quorum sensing" (Fuqua et al. 1994). They explain: "Certain bacterial behaviors can be performed efficiently only by a sufficiently large population of bacteria. We describe this minimum behavioral unit as a quorum of bacteria. LuxR-LuxI type systems provide an effective … way for bacteria to take a census of their numbers" (273). Their framing assigns bacteria a group identity in which they are sensing for a *quorum*, for a census, rather than just for molecules. The

[81] Strictly speaking, Nealson et al. 1970 define autoinduction at the level of the entire bacterial culture, not individual cells: "the phenomenon occurs without external intervention, [so] it must be attributed to a conditioning of the medium effected by the growing cells" (313).

updated terminology presupposes a collective, entirely changing the role of the single bacterium, which rather than acting independently alongside its neighbors is now identified within a larger "minimum behavioral unit." Pre-threshold cells are understood as latently multicellular, awaiting sufficient numbers in order to initiate group action; any autoinduction occurring before meeting the threshold is overlooked. In this new framework, AI molecules are the circulating medium through which group identity is established.

The new terminology quickly became standard in the scientific literature. In 1999, Dunny and Winans suggested that the term seemed "to have answered some etymological need within the microbiology community" (3), however, the shift has sometimes been received by scientists as a metaphor outrunning its experimental basis. Turovskiy et al. describe the coining of the term as a deliberate effort "to come up with a new name that was innovative, descriptive, and most importantly, catchy" (192). They observe that the new term "spread like wildfire, making its way into virtually every paper involving autoinduction written afterward" (193). For Turovskiy et al., "the appeal of all these allegories is understandable, as is the enthusiasm of the researchers who make these comparisons; however, scientific theories cannot survive solely due to their appeal" (193). Other scientists have similarly suggested that the term carries an irresistible appeal that risks misrepresenting the biology: Winzer et al. describe it as "fashionable" (2002, p. 216), while Hense et al. refer to call it an "intriguing idea" that "has received much attention" despite insufficient experimental support (2007, p. 230). In the most sustained such critique, Redfield cautions that "the appeal of the idea that bacteria act cooperatively has caused the postulated benefits of quorum sensing to be accepted uncritically as the explanation for the role of autoinducers in gene regulation" (2002, p. 365). "We seem to be most prone to errors," she continues, "with those processes that

most strongly distinguish us from bacteria… Perhaps because we are social animals, we find the idea that bacteria have evolved communication and cooperation very appealing" (369).

The metaphor contained in the term "quorum sensing" is indeed an anthropocentric one, yet it is certainly more than simply a catchy phrase. It also reveals a serious claim about what bacteria are, assigning them agency as social organisms. The shift in terminology has always been about something larger than mere density detection; its appeal is partly due to the imaginative leap it entails. For a quorum is not merely a numerical threshold expressing the accumulation of autoinducers or bacterial cells. It also signifies a political threshold—a threshold of humans engaged in the work of governing. The word *quorum* refers to "a fixed minimum number of members of an assembly or society that must be present at any of its meetings to make the proceedings of that meeting valid" ("Quorum, n."). In QS discourse, the intended comparison is that bacteria, like the members of an assembly, vote through the secretion of autoinducer molecules; a certain number of members are needed in order to ratify the group's behavioral decision. Fuqua et al.'s definition of autoinduction as quorum sensing, terse though it is, reflects a significant reconceptualization of both bacterial life and its conventional metaphorical explanatory framework.

Other researchers have followed their lead, describing QS more explicitly as a voting procedure. For example, in a 1996 *Science* commentary titled "Bacteria Also Vote," Kaiser describes *Myxococcus xanthus*'s switching into a nutrient-conservation mode as a voting procedure, writing that "releasing A-factors is the way that a cell votes its particular assessment of nutritional conditions. When each cell contributes its vote to the extracellular pool of A-factor, a more reliable choice of response can be made…" (1598). Kaiser likens the process to the staking of opinions, describing individual cells as "opting" for or "choosing" one mode versus the other in preparation for the collective's "important judgment call." His phrasing implies cognitive roles for the cells, with each

one individually choosing and voting before a threshold can be determined. Other scientists echo this language. Federle and Morrison refer to quorum sensing as a process of "organizing a parliament" and "voting."

The premise of bacterial governance is a significant departure from the metaphors traditionally used to describe microbial aggregates. While cell biology has long adopted political metaphors to describe the cooperative interaction of cellular groups, these have applied strictly to multicellular organisms and especially the human body. As a number of critical studies have established, the society of specialized human cells has been historically compared to various political configurations—monarchy, democracy, police state, nation state—in accordance with theorists' own social ideals.[82] Yet despite that variety of political forms, constituent cells are always described as an orderly whole, unified by the common pursuit of bodily function. Microbes, in contrast, have conventionally been represented as swarming, *ungoverned* masses threatening the integrity of the body's well-ordered society. It is therefore quite novel that microbes become civilized—self-governing and responsible—in quorum sensing discourse.[83] In adopting a term referencing political harmony and governance, Fuqua et al. entirely remake the traditional conception of bacteria, inserting them into a metaphorical framework typically reserved for human bodies, genteel and orderly contributors to a sociality of their own.

And this is not just any assembly. The authors specifically invoke a democracy, and a rather perfect one at that. In a subsequent review two years later, they drew overt linkages to the US Constitution and the process of census-taking in a representative government. They write that this

82 Rudolph Virchow's egalitarian politics influenced his theory of the cell state as democracy, while Ernst Haeckel's political views led to his more hierarchical description of the body as monarchical society ruled by a central government; see Weindling (1981), Otis (1999), and Reynolds (2008). Martin describes the metaphorical description of "the body as nation state at war over its external borders, containing internal surveillance systems to monitor foreign intruders" (410).
83 Fishel's study, *The Microbial State*, analyzes this shift in asking how new understandings of human-microbial interactivity require new metaphors that move beyond the inside-outside demarcation of the body politic.

process unfolds in bacteria "with little of the political contentiousness" that characterizes human politics:

> The importance of accurate demographic information is reflected in the United States Constitution, Article 1, which provides for a decennial census of this country's human population. Bacteria also conduct a census of their population and do so more frequently, more efficiently, and as far we know, with little if any of the political contentiousness caused by human demographers. (Fuqua et al. 1996)

Bacteria become demographers tasked with characterizing a heterogeneous population. Significantly, this census-taking is also suggested to affect how the population is to be governed. Article 1 of the US Constitution, referenced in the quote, establishes the 10-year census for purposes of "Representatives and direct Taxes" to be "apportioned among the several States which may be included within this Union, according to their respective Numbers" (*The Constitution of the United States: Article 1, Section 2*). The comparison thus links autoinduction to representation and to voting as a means of political expression. And the action of census taking is suggested to be uncannily harmonious: more frequent, more efficient, and less contentious than the human equivalent. The need for a quorum in the first place would then seem to vanish, since the group as a whole must always agree. The paper is titled "Census and Consensus in Bacterial Ecosystems," a catchy elision that idealizes quorum sensing as a unified political endeavor in which bacteria are model citizens, defined by a counting that is also a decision, a census that is already a consensus.[84]

This is, it would seem, a rather peculiar democratic assembly. The requirement for a quorum in human societies has traditionally existed in order to ensure balance amongst a group comprising

[84] Hense et al. capture this contradiction, noting that "the idea of a minimum behavioural unit implies that the purpose of autoinducer sensing is twofold, both taking a census (has the minimum density for effective action been reached?) and coordinating or synchronizing behaviour, so that the quorum of bacteria functions as a unit" (230).

diverse interests and stakes, providing "protection against totally unrepresentative action in the name of the body by an unduly small number of persons" (Robert et al., p. 21). The quorum mandate thereby acknowledges the inevitability of disruption, dissent, and contention in political process, and the achievement of a consensus that is always partial and contested. The quorum mandate thus acknowledges the inevitability of disruption and disagreement in the political process. It suggests, in other words, the difficulty of forming unity from a society of individuals—a challenge that cannot exist in autoinduction.

And so the question remains: if everyone agrees all the time, why the need for a quorum? Disagreement is in fact structurally impossible in the autoinduction model. An autoinducing cell recognizes only a single molecule; it is not equipped to secrete or respond to differences of "opinion." Its "votes" are only black triangles leaking out and trickling back in—a simple indicator of presence, passively secreted and automatically processed. Standing united is therefore not a virtue so much as a biological default. They stand united because there are no words with which to express dissent. Contained within the term itself is thus a contradictory, idealized image of bacteria as achieving political unity without conflict, of a diverse group of individuals agreeing volitionally.

That paradoxical consensus has been reflected in later researchers' use of the metaphor. For instance, microbiologist Bonnie Bassler describes a process in which "the bacteria cast chemical votes, they tally the vote, and all the members of the community go along with the outcome" ("Microbes as Menaces, Mates & Marvels," p. 73). Similarly, a *Journal of Bacteriology* conference review titled "Cell-Cell Communication in Bacteria: United We Stand," again reproduced the vision of bacterial cells blissfully civilized, engaged in the project of American democracy (von Bodman et al.). Nealson identifies the nomenclatural irony at work in these instances, writing that he has found the name change to QS "quite amusing considering the relative chaos that exists in faculty meetings with

a sufficient quorum present! Perhaps one might prefer a name that implies that the decision is intelligent or useful rather than simply legal" (1999, p. 287-8).

As Nealson implies, intelligence is at odds with the political process invoked in quorum sensing metaphors. Although bacterial governance metaphors do at first seem to promise something radically new, they ultimately collapse into a reinscription of the human-microbial divide by invoking democracy only to confine it to *de facto* agreement. The promise of genteel bacterial governance ultimately constrains because its central metaphor relies on the possibility of dissent and thereby paradoxically highlights the absence of such dissent in autoinduction. The quorum sensing framework therefore confines them to a collective identity in which their agency and individuality are diminished in subservience to the whole. I suggest that it is for this very reason that the governance metaphors quickly became obsolete, replaced by more broadly social terms. But first, a turn to science fiction.

The constraints of QS's early political metaphors can be more fully recognized through examining science fictional treatments of microbial governance. Fiction writers have traditionally echoed cell biologists in their depictions of microbial societies as oppressive, swarming masses. They often represent microbes governing themselves without dissent, as in the early QS metaphors, but here the population is sinister in its uniformity. Science fiction therefore uses microbial governance to create distance, rather than similarity, between humans and microbes.

In fiction, the alterity of microbial governance is often signaled through the conceit of speech. For instance, in the genre of microbiography stories microorganisms narrate their own microscale lives and dramas amongst themselves—a gesture that, as Catherine Belling notes, displaces human subjectivities altogether. On the other hand, microcosmic romances sometimes

imagine humans engaging in conversation with microscopic life in their voyages into the nanoverse. But notably, these stories bypass the possibility of linguistic engagement with the actual microbes (bacteria, viruses) their protagonists encounter in their journeys, which are cast strictly as mortal enemies; the possibility of peaceful conversation is reserved for the humanlike beings populating the nanoverse. The same is true in reverse: stories in which humans engineer giant microbes sometimes grant these beings communicative capabilities, but the opportunity for cross-species communication generally ends with humans gruesomely murdered by their creations. Through these various strategies, microbes—even when they are linguistic beings—are limited to the role of festering multitudes.[85] As such, they reinforce the limits of the QS metaphor even as they anticipate the more expansive imaginings of human-microbial interchange to come.

When microbes do speak with humans in science fiction, their words generally alienate. Microbial speech, because it signals a threatening biological totality, is a horror. Patrick Parrinder has written that in science fiction more broadly, language is as "the central feature of alien intelligence" (51), presenting a communication barrier to be overcome through translation.[86] In the fictions of John Russell Fearn and Greg Bear discussed below, communicative microbes do signal alien intelligence, particularly in their strange modes and patterns of speech. Yet they communicate with humans not so much through *translation* from one language to the next, but rather as an act of linguistic usurpation: they seize control of human language, using it instrumentally as a tool for dominion. Like the genteel democrats of quorum sensing, these microbes communicate via diffusible molecular signals that limit their individuality, symbolizing a dangerous biological totality

[85] On microbiography and the displacement of human subjectivity, see (Belling). Twain's *Three Thousand Years Among the Microbes* promises to do better but in the end simply turns its human narrator into a cholera germ, flattening any possibility of ongoing perspectival interchange (Tuckey). On microcosmic romance, see (Milburn). Giant microbe stories include Couvreur, *An Invasion of Macrobes* and Dutton, "The Beautiful Bacillus" .

[86] On language in SF more broadly, also see Meyers's comprehensive survey of linguistics in science fiction, which, along with Parrinder's analysis, identifies language as a means of challenging biases about other lifeforms.

that prevents voluntary agreement and forecloses the possibility of benevolent interaction with the humans who attempt to converse with them. And so they function within the same narrative constraints as the early QS political metaphors, showing what lurks below the surface when microbes are represented as perfectly uniform societies.

John Russell Fearn's short story "Dynasty of the Small," first published in the pulp fiction magazine *Astounding Stories* in 1936, brings microbes and humans face to face when, thanks to the errors of a short-sighted scientist, bacteria grow into monstrous eight-foot organisms covering the surface of the Earth. Fearn's bacteria also develop something like speech, though instead of words they emit smells that circulate amongst themselves. This mode of communication binds them together in unified collective. There is little possibility of individual expression: the diffusion of dissenting opinions would be drowned out rapidly and diffuse away un-smelled. As in quorum sensing's political metaphors, these monsters stand united, by default.

The humans who wander into the bacterial jungle gradually learn to interpret their smells, which trigger them to experience thought messages when inhaled. They learn that the bacteria possess an awareness of their own cultural history and a claim to undefined "intellectual pursuits." For a brief moment, this scenario seems to promise a new and exciting conversation between the two sides. Yet these bacteria are no more humanlike for their language and intellect. Rather, their form of communication signals a political structure that is entirely hostile. Fearn's bacteria, in society as in language, are defined by their collectivity. They speak to humans through one collective "voice," articulated exclusively through the first-person plural and without any designated spokesperson; the message originates from the group as a whole. They are one ruthless and domineering unit, driven to reproduce and to consume.

In their engagement with humans, they use language solely to overwhelm and to intimidate. The explorers find themselves awash in a sea of strong, foreign, odors that overwhelms them both chemically and politically: the air is thick with "the exotic, overpowering odor of acacia; the heavy and sickly smell of a hyacinth in a heated room; the rank, earthy reek of a full-blown chrysanthemum, so suggestive of the fall and death." Physically surrounded by a suffocating molecular message that they can neither escape nor ignore, the humans are overpowered in a manner that mirrors the overpowering of the landscape that the bacteria have already accomplished.

Their message is inescapable; meaning impinges upon human brains. Fearn describes the scientists' adaptation to bacterial language as a passive and mechanistic adaptation:

> Each day they became palpably conscious of a new meaning to the varied odors. Their olfactory nerves became gradually adjusted to the unexpected conditions … Nerve responded to nerve, affecting, too, the nerves of the brain, until at last, three months later… [they] sensed the first real portents of dawning; revelation entering their minds.

That revelation, chemically encoded, enters their minds unasked and places humans in the position of bacteria responding passively to environmental changes. And what they interpret from this passive reception of alien language is an assertion of bacterial superiority. "Above all," the bacteria say (smell), "understand this: we are the rightful owners of earthly life… Now our turn has come, and we are here to form a dynasty of our own." Throughout the story, the humans remain unable to talk back. In air thick with meaning they switch places with their bacterial captors, becoming silent and non-communicative.

For Fearn, a bacterial population unified in structure and messaging is no virtue but rather a vicious threat akin to the threat of invading microbes overwhelming a human body in a raging infection. Rather than making bacteria more like humans, this vision of bacterial homogeneity

establishes a rift between us and them, pitting a society of individuals against a teeming, and powerful, collective.

Humans, in contrast, are characterized by their inefficiencies. They are unable to control the bacteria and their actions are marked by ineptitude, conflict, poor leadership, and discord. Indeed, they are never able to agree on an appropriate course of action; the crisis is resolved only through the giant bacteria's own errors as, blinded by greed, they overpopulate and die without human intervention. Disagreements borne of individuality are the mark of humanity. Conflict and chaos are in fact the very characteristics of human society that prevent their descent into the menacing multitude that they oppose.

Fifty years later, Greg Bear's novel *Blood Music* would again imagine a collective of linguistic microorganisms overwhelming their human hosts. The novel narrates rogue scientist Vergil Ulam's engineering of an intelligent line of his own lymphocytes ("noocytes") and their reintroduction back into his body, where they develop and begin to overtake their host—eventually moving outward into other hosts.

These noocytes are bound together through an efficient molecular communication network, in which they sense and transmit messages encoded in nucleic acids. This form of communication is fundamentally nonlinguistic, existing to coordinate group action rather than to express individual opinions. This difference is illustrated through biotech entrepreneur Michael Bernard, who briefly takes on the perspective of a noocyte within his body. Bernard finds himself sending and receiving messages that he experiences as physical impacts (molecules, pressures, gradients) upon his body: "he receives, feels the aura and pressure of huge molecular messages from the outside. He takes in a plasmid-like data lump, *ases it, and pours information from it, absorbing it into his being… Now

the lumps come rapidly… he breaks and pours each one" (201). There is a certain ease to Bernard's processing of these messenger lumps and strings. Like Fearn's explorers, he absorbs them without translation: "he seems to almost immediately comprehend the experience of the cells rushing past in the capillary." Even his own thoughts are experienced without agency, arising out of the medium itself rather than from any mind. Bear captures this by describing thought through passive constructions: "it comes to him suddenly" (212); "suddenly he knows" (214); "thought rises above the chemistry" (200).

Within this noosphere, Bernard participates not as an individual but as a member of the collective. While the noosphere comprises a wider diversity of organisms than Fearn imagined for his giant bacteria, they are entirely unified in purpose, working together to execute the orders of the command clusters directing the action. Bernard-as-noocyte senses his fellow cells by the concentration of their signaling molecules, discovering that "the downstream companions are as distant, as chemically isolated as if they were at the bottom of a deep well; the upstream companions are intense, rich" (200). Individual identity is replaced by degrees of proximity within the collective, with cells defined not by the uniqueness of their messages (there is no possibility for this) but rather by their position in space.

And so here is a depiction of microbial society existing in perfect harmony, defined by the "sweetness" and "camaraderie" of shared identity. But where QS invoked harmonious governance as an ideal version of human society, Bear clarifies that such harmony only exists in the absence of dissent and individuality. The noosphere precludes individuation, a concept that Bernard struggles to grasp. Asking to speak with an individual, he is told, "**We have studied INDIVIDUAL in your conception. We do not fit the word.**" The noocytes go on to clarify: "**Information is passed between clusters sharing in assigned tasks… Mentality is thus divided between clusters**

performing a function. Important memory may be *diffused* through all clusters. What you think of as INDIVIDUAL may be spread throughout the *totality*."[87] Across this diffused identity, noocyte society emerges as an inflexible hierarchy. Any hints of individuality are ruthlessly removed. Bernard learns that if any cells "have abandoned the hierarchy—rebelled or malfunctioned drastically—the virus particles move in and inject their package of disruptive RNA. The offending cells soon explode" (211). This brutality ensures the functioning of the whole; the harmonious and efficient microbial society is not produced by cheerful agreement as in QS so much as by the constraints of the microenvironment and the expulsion of dissent.

As a unified, enforced hierarchy the noocytes are entirely irreconcilable with humans. Coexistence is simply impossible, a point that takes shape through the novel's use of language at the human-microbial interface. The noocytes, in addition to their own signaling pathways, are masters of human language. Within only days of their injection into Vergil's bloodstream they initiate conversation with their host. Without warning, the reader slips along with Vergil into the strangeness of their form of English:

> **[N]: SPOKEN with other**
>
> [V] —What?
>
> **[N]: WORDS communicate with *share* body structure *external* is this like**
>
> ***wholeness WITHIN* *totality* is EXTERNAL alike**
>
> [V]—I'm not understanding, you're not clear.
>
> …
>
> **[N]: YOU *interface* *stand BETWEEN* EXTERNAL and INTERNAL. Are they alike**

[87] The distinctive formatting of noocyte speech in *Blood Music,* with its bold face type, capitalizations, and asterisks, is reproduced here.

—Inside and outside? Oh, no.

Are OUTSIDE *share body structure* alike

—You mean Edward, don't you? Yes indeed . . . share body structure alike.

EDWARD and other structure INTERNAL similar/same

—Oh yes, he's quite the same except for you…

This passage narrates the noocyte's growing awareness that *words communicate* between humans, in this case, between their host and his friend Edward. It is a foreign concept to them; they understand only unity, not separateness, and therefore have no need for words. Ria Cheyne has noted that the use of created languages in sf often "signifies that 'This is alien' … [and] communicates the difference of the beings that speak it" (392). Although Bear's depiction of the noocytes' speech is less a created language than an imperfect translation, it resoundingly signifies the alienness of its speakers with its heavily accented with asterisks and boldface type, jarring in its inconsistent grammar and capitalizations.

The alienness persists. Bear declines to represent noocyte speech as an opportunity for mutual conversation between two linguistic societies. Rather, his noocytes adopt English instrumentally. The noocytes seize human language in order to recruit people into the noosphere, through which they are bodily dissolved into sheets of tissue that cover the surface of the Earth. In this form humans retain some consciousness, they primarily cede to the collective. Language becomes obsolete.

And yet the novel insists that this dissolution is not a nightmare, but rather a utopian vision of transcending the constraints of language and individuality. Bear has written of *Blood Music* (the 1983 story version) that "what at first seems an unmitigated horror is in fact much more, if we could only take off the blinders of our mortal individuality" (Bear 2002, p. 15). Indeed, the bright dream of

Blood Music is the overcoming of human corporeality and all its limitations. Through fusing harmoniously into a collective, the ache of humanity's existence in separate bodies is overcome.

Broken language is a marker of the "mortal individuality" that Bear challenges readers to imagine overcoming. The novel consistently identifies human speech the necessary but ineffective bridge between individuals occupying separate bodies. Language breakdowns of all kinds figure prominently. Vergil himself seems genetically impaired in his ability to connect with others, having a voice that "seemed designed not to win friends—harsh, slightly grating, tending toward loudness." His voice is consistent with a general physical unattractiveness that is suggested to prevent social and sexual contact with others. The noocytes resolve his physical insufficiencies, but also drive him into further isolation. His relationship with his girlfriend Candice, for instance, descends into lapsed and broken conversations until she pleads, "You get all crazy and I don't understand you … Please, make sense." Other characters are also defined by their inability to connect. Bernard's quarantine in a German isolation chamber after his infection typifies a lifelong pattern of toxic romances, professional isolation, and dead-end conversations. Within the chamber, the noocytes drive him away from his last remaining friend as manifested in a series of stilted conversations:

> They stared at each other through the threelayer glass. Paulsen-Fuchs tried to speak several times, but nothing came out. He lifted his hands helplessly.
>
> "Yeah," Bernard said, sighing.

Likewise, the character Suzy is a young woman with an unspecified intellectual disability that marks her as "slow"—a state she dislikes and which limits her to trivial pursuits (magazines, fashion, boyfriends) and ineffective navigation of New York's apocalyptic landscape.

Each of these characters is prevented from interacting fully with others because of physical, emotional, or intellectual barriers beyond their control. The novel stages no reunions within the

human world; the noocyte takeover only leads to ever greater loneliness. That separateness is further enforced by the precarious communications systems that humans rely on. For instance, the only plane capable of surveying the wasteland of North America sends back a radio stream that breaks up at pivotal moments before cutting off entirely in a catastrophic accident. Meanwhile, Suzy is sentimentally attached to an old radio that she carries with her through the empty New York streets. It transmits news broadcasts that are almost unintelligible ("the speaker produced a weak voice, hashed with interference, like a man speaking through felt") and which are uninteresting to her when decipherable. She clings to the radio simply because it is "the only human thing she had left, the only thing that talked to her." Suzy's condition encapsulates the isolation of *Blood Music*'s entire cast of characters, before and after the noocytes arrive: they are constitutionally unable to communicate, driven apart by biological and intellectual differences and constrained by a rickety communications network.

The noosphere, in contrast, offers to fix all of these deficiencies. Biologically grounded and ruthlessly efficient, noocyte signaling is susceptible to none of the fragilities of human communications. In the ebbs and flows of meaning-laden molecules that bind together the group as a whole, the need for language disappears. The novel's utopian vision entails the resolution of the profound insufficiencies of human language. Though foreign, jarring, and incomprehensible in translation, noocyte communication promises to heal the pain of human individuality.

Humans entering the noosphere find their intelligence sharpened, their separateness eliminated. They are even able to virtually revisit, and revise, moments of loss from their past. Bernard corrects his various interpersonal transgressions, with the novel closing on a conversation with a long-lost love interest and the promise of "another chance." Suzy enters the noosphere on the promise that her intellectual disabilities will be remedied—that she will "be a lot smarter now."

Once inside, she finds that "she was not the same. Something in her had been bypassed—the part that made her slow." She ultimately receives confirmation that "they fixed people," to her relief: "'Good. I'm awful tired of being slow.'" In this version of her perfected self, she is accompanied by the family she had lost: "She was all Suzy, and all her mother, and all the others individually, but *together*."

Blood Music, then, rejects language as a means of forging meaningful connections either between humans or across the micro-macro divide. Language is symptomatic of the painful division of humanity into separate bodies and minds and therefore must be left behind. At the same time, however, Bear strips humans of that which makes them different. Disability, physical imperfections, personality differences—all of these are erased. As Stephen Dougherty has written, the novel describes "a utopian transformation, a radical and democratic leveling of all identities and states of being" (106). Speaking with microbes means surrendering the variability and diversity of humanity. Democracy comes at the expense of the individual.

In both fictions, the conflicts and communication breakdowns resulting from humans living together in heterogeneous societies are set against the threat of inhumane microbial collectives. Together, they anticipate both the promise of QS governance metaphors and their constraints. While scientists' voting and democracy comparisons are surely driven by a humanizing impulse, they fall short of achieving it. This first wave of metaphors, in describing consensus without dissent, in failing to individuate the bacterial actors, ultimately recapitulates science fictional visions of the antagonistic microbial swarm.

In science fiction and in scientific metaphors, however, the longer trajectory has been toward a greater individuation of microbes, liberating them from their impossible democracies, their

hierarchies and collectives. Over the following 15 years, quorum sensing's successive metaphorical frameworks and the fiction of Joan Slonczewski, linguistic interaction between humans and microbes is more bidirectional. Communication between humans and microbes becomes conversational, no longer premised on the ceding of control and dissolution of self. Rather, it preserves the individuality of both sides as they work to forge a shared language, together.

3. Metaphors of Quorum Sensing: Bacterial Sociality

The grim prospect of bacterial hordes captured in science fiction was soon undercut by the changing metaphorical boundaries of quorum sensing discourse. Within just five years of the advent of "quorum sensing," scientific discourse had already left behind its overt political references even if it still retains the term itself. In their place arrived a constellation of language, speech, and sociality comparisons. This shift brought a more flexible heuristic model as well as wider imaginative possibilities. Rather than defining microbial collectives as simply homogenized, language comparisons imply the possibility of varied messages sent and received by distinct individuals. They also enable a reaching beyond the boundaries of species. Cara Hustak and Natasha Myers have discussed the challenge posed to plant biology by the diffusion of volatile organic compounds, a "*volatility* that gets read as a kind of *vocality,* a way of speaking in a chemical vocabulary" (100). They argue that this vocality amounts to an affective, creative practice for plants that upends their traditional status as non-interactive organisms; this shift has required chemical ecologists to ask "what precisely constitutes a subject or a sign in what appears to be an effusive ecology, overflowing with messages and meanings" (102-3). Microbiologists, in casting bacteria as conversational agents, are asking the same questions. In both cases, vocality forces a renegotiation of how humans might relate to lifeforms once thought to be silent. The prospect of QS as a language—and therefore as a

translatable message—involves the possibility, however fanciful, of humans talking back. This is the crucial step that would enable the eventual imagination of brain-microbiome conversation.

The shift originated primarily with Princeton microbiologist and quorum sensing evangelist Bonnie Bassler. Although she was not the first to describe autoinduction as a language, she is responsible for engineering the particular contours and humor of the metaphor across professional and public scientific discourse.[88] The comparison began with a prominent 1999 review article titled "How bacteria talk to each other," published in *Current Opinion in Microbiology*. Here Bassler introduced a series of witty language references to describe different aspects of quorum sensing biology. For instance, the various molecular classes of QS molecules are described as different languages, Gram-negative bacteria with "the LuxI/LuxR language" and Gram-positives having "their own language." A particular strain of marine *Vibrio* that combines both systems is described as having "hybrid languages." Language references are also used to describe conversations between different kinds of bacteria (they speak a universal "bacterial Esperanto") and in complex communities (populated by "multilingual bacteria"). Bassler does not elaborate on these comparisons in detail. Nevertheless, they describe a particular mode of relationality that would soon typify QS's language metaphors, in framing bacteria as both speaking and listening.

Bassler's metaphors quickly became widespread and progressively more elaborate across scientific publications. Journal articles and scientific commentaries steadily deepened the autoinducer-as-language conceit while seeming to insist on a genuine similarity between human speech and QS. Thus, autoinduction is said to be comprised of "diverse chemical languages"

[88] Comparisons between cellular signaling and forms of human communication was not entirely new; see early hints in Kaiser and Losick (1998) and Gray (1997), for instance. For decades, cell biologists had relied on terms like *cross-talk*, *communication*, and *talking* to describe molecularly-mediated interchange between cells. These usages have generally been fairly restrained, referring without elaboration to the exchange of and response to signaling molecules. QS discourse, in contrast, quickly began to describe autoinduction in a particularly whimsical manner, attaching meaning to these signals as a signifier of microbial sociality.

(Bassler 2002), "dialects" (Brameyer et al.) or to be a "chemical lexicon" (Winans)(Henke and Bassler). It is a "vernacular" (Bassler 2002) (Sifri), comprised of "words" (Bassler 1999) and "vocabularies (chemical signal molecules)" (England et al., p. xi). Across these and other examples, bacteria are credited with a much broader range of capabilities than in the original voting metaphors, entailing messages that go beyond the simple yes/no of a voting procedure.

This conception of bacterial language has also enabled the imagination of bacteria as interacting socially through speech. Perhaps because the biology of QS involves populations acting smoothly as one unit, those interactions tend to project the same paradoxical group harmony I outlined with the voting references. Yet this time, it is without the constraints of perfect agreement; as linguistic beings, autoinducing bacteria are suggested to exist in societies of individuals—not a homogenized democracy so much as a charming, pleasant society. The talking bacteria of QS appear to be unconcerned with serious matters like political processes. Quite often, interactions are described as having a sort of lazy, casual sociality. Bacteria are said to engage in "conversation" (Joint et al.), "chatter" (Visick and Fuqua), "chit chat" (Joshi et al.), and "small talk" (Bassler 2002). Strategic attention to the banter of other species can be referred to as "listening" (Joint et al.) and "eavesdropping" (Gray) (Joint et al.), the potentially combative overtones humorously smoothed over. And perhaps the culmination of this metaphorical line: a review article titled "Bacterial tweets and podcasts #signaling#eavesdropping#microbialfightclub" (Michie et al.). Thus the threat of ominous uniformity is defused, through humor and the depiction of a harmonious bacterial society comprised of distinct and opinionated individuals with things to talk about.

The biology of QS, as discussed previously, does not in reality support such a conception; speech comparisons overstate both the intentionality and the directionality of autoinduction. If QS is to be understood as a language at all, it is one comprised for any given species of just a single

word—a simple "I'm here!"—and not a "rich" or "diverse" vocabulary. Other content is not possible, let alone conversation or chatter; there are no words to combined, no interpretations or creative phrasings. Communication happens not through variety of messages but rather the amplification of that single word in parallel with increasing population density. Further, even the act of "speaking" cannot actually be conceived of as such, as there is no articulation when it comes to signaling molecules. Autoinducer secretion, rather than responding to any particular impulse or condition, is a constitutive state in which bacteria unceasingly emit molecules, continually and passively leaking "words" into the extracellular environment. Meanwhile, the speech framework fails to describe a cell's responsivity to its own molecules. As with the voting metaphors, it shifts the functionality of the system to the group level so as to entirely exclude any functionality for self-talk (self-autoinduction): the metaphor defines the primary purpose of microbial speech as the sending of messages between distinct entities.

And yet. Despite this mismatch between metaphor and molecule, we cannot simply take QS metaphors to be a bit of idle humor, to dismiss them as "principally pragmatic or heuristic," as philosopher Pamela Lyon does (829). Rather, I argue that the shift from political uniformity to happy society reflects a genuine effort to individuate bacterial cells to the greatest extent possible, imbuing the idea of microbial speech with its particular surprise and humor. Scientists themselves are cognizant of this; the identification of QS as a paradigm-breaking model is commonplace. Winans writes of the old perspective in which bacteria "were thought to live rather reclusive lives" (2002, p. 83), Kaiser and Losick of "the traditional view of a bacterial cell as a self-contained entity" (1993, p. 883), Dunny and Winans open their volume on cell signaling (broadly understood) in bacteria with an introduction titled "Bacterial life: Neither lonely nor boring" (1). These sentiments

are echoed broadly across the QS literature, together constructing an argument for the whimsical image of chit-chatting microbes as more than just idle humor.

In its place is a growing suggestion that bacteria are more *like us* than previously known, with language metaphors diminishing divisions between the domains of life. Across the QS literature, the argument for the humanlike qualities of bacteria—their creativity, diversity, and capabilities—is occasionally stated directly, especially in papers discussing signaling between different bacterial species. This form of QS, which depends on classes of autoinducers recognized by multiple types of bacteria, contributes to the development of multi-species complexes like biofilms. It is here that the strongest claims for autoinduction-as-language tend to cluster. Jakubovics, for example, describes biofilms as resembling human communities, with structures similar to "the bustling office blocks and apartment buildings of busy cities" and "channels and voids… like roads and alleys running between tall buildings" (4). He observes that the emergence of these bacterial cities requires language, writing that "social and communication networks are the lifeblood of large communities" (4). Language, in other words, is the circulating vital force that binds individuals, whether bacterial or human, together across space. He continues: "Building a city is a complex process that requires input from a wide variety of specialists, from town planners and architects to engineers and labourers. Effective communication between workers is essential for the smooth running of the operation. In the same way, bacteria building oral biofilms adopt specialized roles and communicate with one another" (4). Without communication, no city. Jakubovics describes bacterial language as solely productive of a flawless and complex microbial collective—productive, in fact, of multicellularity itself.

In a similar vein, Kolter and Losick's (1998) research commentary in *Science* draws parallels between biofilms and early human society, both of which are held together by language:

> Communities form by interactions amongst individuals. In the beginning, a few wandering souls find an appropriate location in which to settle. As the population numbers increase at this spot, individuals must communicate closely to ensure adequate distribution of food and removal of wastes. If successful in these early stages, new communities can flourish and stabilize and their members can enjoy the shelter afforded by living in a protective environment.
>
> These words could describe the growth of a village, but the same description can also be applied to community formation by the simplest of all organisms, the bacteria. Despite the widely held view of bacteria as primitive, unicellular organisms that struggle for individual survival, it is becoming clear that bacteria seldom behave as isolated organisms. Rather, the apparent simplicity of bacteria belies their extraordinary sophistication in communicating with one another and sometimes with higher organisms as well… (226).

In this excerpt, language is described as the critical influence on both bacterial biofilms and primitive human societies. Growth, shelter, and enjoyment are all said to derive directly from sophisticated, close communication. Language-like signaling thus mediates a community development that is imminently multicellular; bacteria are but a few developmental steps away from emerging into humanlike society.

The transformative power of speech is integral to these conceptions: a biofilm exists in all its intricacies because its residents are *talking,* not merely secreting molecules passively. The speech and society metaphors deepen the sense of individuation, of humanlike subjectivities interacting as we do. It also reflects the transformative quality of the speech metaphors in the first place, namely, their capacity to surprise readers into a newfound wonder at the capabilities of microbial life.

The humor and surprise intrinsic to these metaphors are perhaps best recognized by science fiction author and practicing microbiologist Joan Slonczewski, who is uniquely placed to mine the depths of the talking-bacteria conceit. Her novels *The Children Star* and *Brain Plague*, which extensively pursue the novum of human-microbial conversation, were published in 1998 and 2000, exactly at the transition point between QS's two metaphorical stages. The novels narrate the developing symbiosis between humans and the "micros," an intelligent microbial species that establishes habitats in their brains. The novels continually present humans wrestling with their preconceptions as they encounter micros for the first time, in lock step with the reader: aren't infections bad? how do we know they won't overtake us? Yet this is a symbiosis, not an infection.

Slonczewski's micros are bound up in the tropes of quorum sensing discourse. They foreground the speech metaphor's intrinsic humor, as well as the surprise it engenders in its audiences. When *Brain Plague*'s main character, Chrys, first enters into conversation with her new micro population she sounds much like Bonnie Bassler and other QS scientists. Considering the prospect of her micros' arrival, she thinks, "Microbial 'immigrants'?" On learning that her micros look on her as a god, a sardonic "microbial superstition." Her surprise is also the reader's, for both encounter, or marvel at, "microbial cocaine" azetidine/methadone/dopamine, "microbial juvenile delinquents," "microbial wars," "microbial justice," "microbial friends," "microbial history," "microbial portraits," "microbial defectors," "microbial gossip," "microbial world federation," and "microbial rejection." These phrases mirror the structure of QS language metaphors in the unexpected conjunction of the adjective "microbial" with human objects or practices (microbial linguistics, microbial Esperanto). And a passing reference to "microzoöid linguistics" in *The Children Star* might almost pass as a typo in Bassler's 1999 review article. Across these instances, Slonczewski

captures the novelty of encountering organisms previously thought to be silent in their social, linguistic fullness—whether in science or in fiction.

However, Slonczewski's micros are not bound by the limits of biology. They escape the constraints of communication via diffusible molecules, expanding the scope of microbial speech to attain the fullest expression of QS's impulse to animate, narrate, and interact with microbial life. The micros communicate by means of flashing lights encoding meaning in prime number sequences, each individual organism possessing its own distinctive color.[89] Flashes of light retain their color; they don't dissolve away into a growth medium as autoinducers do, or become subsumed into the message of the collective as in previous fictions. Rather, the lights emitted by Slonczewski's micros carry across space and across scales, preserving the messages they encode. This striking departure from biology and from fiction, critically, enables the micros to communicate with one another, and eventually with humans, *as individuals*. Micro speech is a true language, an embodiment of the "rich" and "diverse" chemical languages of quorum sensing.

By virtue of their linguistic capacity, Slonczewski's micros exist in complex societies of individuals. They have unique colors and also unique personalities: some love chess, or libraries, and some go to nightclubs and get high on dopamine, make art, or solve problems. Each micro develops its own life history, personality, and goals. As a group, they share a cultural history that preserves individual contributions and group knowledge, safeguarded in "elder" cells whose longer lifespans enable the transmission of community knowledge. Slonczewski, in other words, depicts micros as rather accurate replications of human individuals and societies despite their differences in scale, a point emphasized in the human characters' gradual shift to referring to them as *micromen* or, eventually, *people*. Her representation of microbial societies demolishes the conventional tropes of

[89] Slonczewski's use of glowing micros recalls the earliest work on bioluminescent marine bacteria, discussed in section 1.

bacterial societies as idealized democracies and ruthless collectives, portraying micros that struggle to reach consensus because of their composition of distinct individuals. Their disparate interests and personalities result in constant clashes that must be resolved through laborious political negotiations, both amongst themselves and with their symbiotic partners. Consensus is possible, but never happens by default.

The drama of *Brain Plague* and *The Children Star,* however, lies not so much in the novelty of complex microbial societies but in the way those societies interact with humans. Language translates, across the differences of scale, species, and lifespan. When micros talk, humans are not only bemused at the prospect of a chattering society similar to ours; they are also invited to talk back. The novels describe the forging of new relations between human and micros as they become conversational partners, upending the divisions that have long held them apart.

This possibility of speaking together has, after all, always been at stake in scientific metaphors of bacterial communication, though scientists themselves would not state it quite so directly. Yes, the conceit of bacterial language is primarily a heuristic device, encouraging a recognition of similarities between human and microbial collectives. But the possibility—the dream?—of talking *with* germs is also latent in the conception communicative bacteria. Interpreting autoinducers as language rather than mere code or consensus vote makes possible the prospect of sending and receiving messages across scales, transcending both the explanatory and imaginative limitations of early QS political metaphors.

There are a handful of instances, scattered across the literature, where quorum sensing is suggested to actually *equate to* human speech, not merely resemble it The strongest version of this

conceit comes from Winans and Bassler, engineers of the original voting and speech metaphors. In a 2002 review of a conference on cell-to-cell communication in bacteria, they led with the following:

> Several hundred millennia ago, prehistoric humans learned that there is often strength in numbers. The evolution of speech likely aided in the ability of protohumans to coordinate the behavior of the group. It has recently become clear that bacteria made this discovery at least a billion years earlier, and in lieu of speech, they evolved a rich lexicon of diffusible chemical signals. In the past decade we have learned that bacteria use these signals to communicate both within and between species. (873)

This is the speech metaphor in its strongest possible form, in which human language is described as a successor to the language bacteria discovered long ago. Further, the authors suggest that the "rich lexicon" of chemical signals can be understood as being *in lieu of* (in place of, or equal to) the lexicon of human speech, with similarly transformative results.

That possibility culminates in the epigraph by Carl Sandburg heading the article: "I am the mob, the crowd, the mass. Do you know that all the great work of the world is done through me?" Notably, Sandburg's poem actually begins, "I am the people—the mob—the crowd." In abbreviating the poem, Bassler and Winans transpose a poem about human society into the voice of a bacterial aggregate. It is the bacteria who speak, performing the conceit of bacterial signaling as language to argue for the restoration of bacteria to their rightful place as interlocutors. The "I" of the bacteria meets the "you" of the human. The epigraph ends with a question mark, leaving us to consider how we would answer this claim to microbial subjectivity.

The implication is factually absurd, of course. I am not suggesting that scientists are actively attempting to chat up their microbe friends. But what might seem mere exaggeration by two metaphor-happy scientists is perhaps the inevitable culmination of the imagination of microbial

speech, whether in science or in fiction. It is a gesture frequently hinted at, if never fulfilled, in QS literature when describing the role of scientists in understanding bacterial messages.

Though the bacteria described in QS papers are often described as happily chattering away in their own rich vernaculars, when it comes to their relationship to human interlocutors, they fall strangely silent. Often the same texts that are rife with witty conversational metaphors quickly switch to something more basic and solvable as pertaining to scientists: their language becomes a code to be *cracked, deciphered,* or *decoded.* For instance, Bassler writes that "the key now for understanding these complex and fascinating bacterial languages is to decipher the impact of the words" (1999, 586). Bassler describes bacterial language as both intricate (complex, fascinating) and solvable (key, decipher) at once. Likewise, the preface to a 1999 volume on bacterial signaling indicates that its chapters "will attempt to decode and translate the different languages" used by microorganisms (England et al., xi). Discussions of scientific efforts to foil QS pathways as a therapeutic target also sometimes put humans in the position of message manipulators rather than conversational partners, as in Alagarasan and Aswathy's review article titled "Shoot the Message, Not the Messenger—Combating Pathogenic Virulence in Plants by Inhibiting Quorum Sensing Mediated Signaling Molecules."

The reversion to decodable, simplified versions of microbial language in these instances is perhaps understandable considering that QS is not a real language to begin with; the role of the scientist engaging with these systems is in fact closer to decoding than to speaking. Nevertheless, decoding might yet be seen as an attempt to enter the communicative realm of linguistic bacteria through the forging of a common language. And so, at least within the bounds of autoinduction research, bacteria remain constrained in their conversational possibilities. Though existing in busy

humanlike societies, they are not yet full conversants. They would become so only in the microbiome era, as the brain entered into the communicative circuit.

In her narration of the developing conversation between human and micro partners, Slonczewski most fully exposes the interactive possibilities of linguistic bacteria, anticipating the eventual development of gut-brain-microbiome axis speech metaphors. When human and microbial intelligences collide, there is no short-circuiting (devolving into coding metaphors); there is no disintegration of the human voice. Rather, the communication itself is a collaborative process. *The Children Star* narrates the long process of forging a means of translating from one size and timescale to another. It begins with Brother Rod's first recognition that the lights flashing on his retina are attempts at communication and his first tentative efforts to teach his micros words. Other humans take on the tasks of identifying patterns in the flashes and of identifying commonalities between human and micro languages. Meanwhile, the micros learn to slow down the rate of their flashes to accommodate humans' slower processing time and to shape their lights into readable letters. This is not language used instrumentally, as in *Blood Music*. Instead, the two parties seek to build a communicative framework together, not for purposes of control but simply in the name of peaceful coexistence.

The result is a radical expansion of perspective that adds to, rather than suppresses, the human voice and body. In this sense, Slonczewski's fiction is the speculative endpoint of the conversational dream encoded in QS's fanciful metaphors: language is the foundation of an inter-species respect and collaboration. This vision of human-microbial interchange exceeds the constraints previously established in fiction and in scientific metaphor. Fearn's giant bacteria and Bear's noocytes are so radically different that they must oppose and consume their human listeners;

autoinducing bacteria, even when existing in happy societies, are accessible only through the work of decoding. In contrast, Slonczewski's micros and people join together with each entity preserving its own identity and uniquely contributing to their developing symbiosis. An instructive example is *The Children Star*'s character 'jum, a young girl who is at first isolated by her intellectual differences. She is shy, aggressive, indifferent to human social cues, and obsessed with numbers, to the extent that other characters struggle to accept her when she arrives on Prokaryon. But where *Blood Music* presents Suzy's differences as problems to be resented in life and then resolved in the noosphere, *The Children Star* valorizes what makes 'jum different. Her skill with numbers becomes crucial to the humans' efforts to translate the microzoöid language. Indeed, 'jum becomes perhaps the most effective communicator of all, as rather than relying on intermediate translations she alone is able to converse with her micros in their original numerical language.

In her graphical depiction of micro communication, Slonczewski echoes Bear's noocytes with their distinctive and alienating patterns. She conveys microbial words in the form of bold-faced strings of numbers encoding messages; 'jum's translation is in parentheses. But their messages are not a usurpation of language for other purposes; instead, it represents mutual respect and a genuine translational effort:

> 'jum focused on a tiny green speck of light. The speck … extended loops of polysaccharide filaments toward 'jum, as if to caress her.
>
> (My name is:) **10037**. The whole shining torus flashed at her. (What is your name?)
>
> 'jum thought this over. **10000101**, she said, picking some of her favorite primes.
>
> (A beautiful name, **10000101**. Your elders must love you very much.)

There is tenderness in this exchange, a reaching-toward with warmth and affection, made possible by the fact that this human is talking not to a teeming mass of microbes but to only one.

'jum is changed by these interactions, as all humans are. Engagement with the micros gives her access to a new expressivity that also brings her into closer relation with her human companions. Unlike Suzy, neurotypicality is not a prerequisite for human belonging. 'jum persists in her uniqueness, choosing to live apart from the colony and continue studying the micro language. But her separation is no longer an isolation, as she is eager for visitors and newly conversant with the rest of the colony. Mastering the micro language, that is, removes what is painful in 'jum's life while preserving her unique capacities: an integration without loss of self.

Collaborating on communication across scales also prompts a broader integrative effort in *The Children Star,* in which the act of speaking together produces an all-encompassing ecological integration. Before the arrival of its human colonists, Prokaryon had been a world defined by its ecological and linguistic synchronicity. Through the amplification of their light signals, micros are able to communicate across long distances and across species lines, with the planet's diverse lifeforms—micros, whirs, tumblerounds, singing-trees—combining through language into a harmonious ecosystem so unified that it can act as one entity. For instance, hostile visitors find themselves expelled by violent meteorological events coordinated through this planetary communicative network. Humans are at first entirely excluded, both physiologically and linguistically. In order to adapt to Prokaryon's "alien ecology, full of arsenic and triplex DNA," they must invest in the laborious and costly process of "lifeshaping." But not recognizing the significance of the lights flashing around them, they are still excluded from the ecological community into which they have stumbled. The ability to speak with micros changes everything. As the symbiotic partnership grows, the micros begin to accelerate the lifeshaping process, ensuring human survival on their planet. In other words, as humans step into the web of chatter that spans Prokaryon, they experience an integration that is at once linguistic, physiological, and ecological.

Slonczewski's novels, in literalizing the linguistic potentialities only hinted at in QS writing, illustrate the radical shift in perspective entailed in the concept of a talking microbe. True cross-domain communication is more than mere lighthearted banter, resulting in the reconfiguration of entire societies. In *The Children Star,* learning to speak with the very small stimulates collaboration with other human groups, as well. The Spirit Colony to which 'jum belongs undergoes a theological expansion. Having long grappled with religious differences that have preventing the faltering colony from accessing the aid it desperately needs, its leaders learn to form alliances with other orders in a spiritual integration that yet preserves each group's unique attributes—a mirroring of 'jum's adaptation to the colony itself. On a wider scale, the incorporation of humans on Prokaryon establishes a new interplanetary order that resolves a longstanding political conflict spanning the entire Fold and which centers on recognizing the intellectual capacity of its microbial life. In a profound sense, then, talking with microbes culminates in an ecological, physiological, and political harmony that resolves longstanding tensions across the Fold.

Which is not to say that harmony is a given. The novels emphasize the fragility of political and ecological unity across scales. *Brain Plague* narrates the threat of microbial usurpation, as humans who have adopted their own micro colonies must constantly work to shape the development of their symbionts lest they misbehave, carried away by their own goals and projects. These episodes, though they appear at first to reinforce the teeming-hordes trope, ultimately reaffirm Slonczewski's central thesis relative to microbial communication: that consensus is at odds with individuation, never a given but rather always laboriously constructed. Precisely because the micros are a heterogeneous society resembling humans' in their complexity, there must also be a constant threat of discord and revolt. Yet it is a threat neutralized by the possibility of speech and the coming together of two consciousnesses through language and a recognition of similarity.

4. Gut-brain-microbiome Axis

By 2014, it seemed as though Slonczewski's vision of internal human-microbiota conversation may have materialized in the real world. Research into the GBMA was consolidating as scientists clarified its role in intestinal disorders and mood disorders, as well as the signaling pathways mediating its connections.[90] In popular science, such research was frequently presented as a communicative circuit whose existence forced a renegotiation of human agency in relation to microbes. In a 2014 article in *The New York Times*, science writer Carl Zimmer reported on recent findings that the gut and microbiome interacted. His article recognized the shifts of its moment, positioning the nascent field as complicating early pop-cultural depictions of the microbiome. In the past few years, he writes, "we've become really familiar with [the microbiota]. Recent research has given the microbiome a cuddly kind of fame. We've come to appreciate how beneficial our microbes are." With a dose of sarcasm, he observes that microbes are generally depicted as "a lovely, invisible garden we should be tending for our own well-being." But this is not the full story. "Maybe," he muses, "the microbiome is our puppet master." Citing research showing how gut bacteria can use signaling molecules to alter the chemistry of the brain, he asks whether food cravings might be understood as the outcome of microbial efforts to "manipulate us."

Microbial manipulation is the implication of the illustration heading Zimmer's article. In the cartoon, a hapless man is tapped on the head by a disembodied hand emerging from an enlarged image of the bacteria living in his gut (Figure 32). Eyebrows raised, he is having a thought—cake!—as he cracks open the fridge. In the text of the article, the point becomes clear. Citing a researcher from the study who comments that people crave chocolate even though it contains no essential

[90] For representative scientific review articles from this time period, see (Martin) on the GBMA's influence on bowel disorders such as irritable bowel syndrome, (Foster and McVey Neufeld) on its role in anxiety and depression, and (O'Mahony et al.) for discussion of neurotransmitter signaling pathways.

nutrients, Zimmer wonders whether "the certain kinds of bacteria that thrive on chocolate are coaxing us to feed them." In this telling, the microbiome is a wily thing, one that we must both tend and tame for our own benefit, even at times telling it "no."

Figure 32. Excuse us, said the bacteria, but we need some cake. (Zimmer).

Zimmer acknowledges that "the idea that a simple organism could control a complex animal may sound like science fiction." The point was not lost on Slonczewski, who shortly afterward linked to Zimmer's article and reproduced its lead image on her blog, *Ultraphyte*, under the title "Bacteria Tell Us What to Eat." Slonczewski's version presents gut-brain-microbiome interchange as a linguistic act (of bacteria *telling* us) and one that not only resembles science fiction, but in fact postdates it. Her post reflects on the puzzlement of her early critics when *Brain Plague* was released, recalling that "reviewers sniffed that microbial aliens were 'impossible.' They didn't ask the microbiologists." The implication is that 1990s science might have validated the novel's talking microbes—but also that her fiction and science have together anticipated the provocations of microbiome research. Linking to Zimmer's article, she writes: "today, the microbiologists are homing in on our gut microbiota. 'Take me to your leader' may mean taking a look inside your gut."

But if the research under discussion seems in some ways to validate the intuition of science fiction (yes, we have intelligences within; yes, they converse with us), these early depictions of GBMA research stop short of the full force of the science fictional precedent. For Zimmer and Slonczewski, the microbiome is an alien takeover or a puppet master: a one-way communicative circuit that dictates but does not receive. The microbiome remains in charge, humans subservient to its whims. However, what first seemed a microbial takeover has more recently come to resemble the possibilities Slonczewski first identified in the concept of microbial intelligence. Comparisons to aliens and puppets have rapidly given way to the same idea animating Slonczewski's novels: conversation, and with it collaboration.

As microbiome research has shifted into its current focus on functionality and therapeutic intervention, it has set forth a changing role for the humans who play host to their microscopic inhabitants. Discovering the pathways through which microbes impact the brain means that the influence might be reciprocal, with humans shaping the microbiota to produce particular outcomes. In this more collaborative vision of symbiosis, human bodies come back into the foreground, joined with microbes and brain in an integrated communicative circuit. No longer headless and disembodied, human desires and physical wellbeing are back in the picture.

In the past five years, popular science writing on the GBMA has harnessed the liberatory potential that has always been embedded in the imagination of speaking bacteria. The speech and language metaphors now attached to this field remain as provocative as ever, but here the bacteria are not just chattering amongst themselves. Instead, they are figured as existing in *conversation with* a human interlocutor. The tropes and themes of microbial speech are particularly pronounced in discussions of the work of John F. Cryan, one of the most visible researchers in the field of "psychobiotics" (and among the authors of *Psychobiotic Revolution*, referenced in this chapter's

introduction). In his own scientific and popular science texts, and the swirl of media reporting that takes up his work, human actions intended to influence the composition of the microbiome are recurrently figured as speech acts. As such, they suggest a reassertion of control, mediated through the uniting of bacteria and humans as conversational partners.

Metaphorical suggestions of human-microbiomic conversation build on the precedent of quorum sensing speech metaphors. In GBMA discourse, microbes tend toward reprising their role as irrepressible chatterboxes. Writers sometimes discuss microbes conversing amongst themselves using the familiar facts and tropes of QS. *The Psychobiotic Revolution*, for instance: "Microbes communicate using hundreds of chemical signals, and if you could tune in, the conversation would be deafening. Bacteria talk to members of their own species, but they also talk to different species and even different kingdoms of life swarming inside your mouth" (90). This is not a conversation to which humans are privy; we are unable to "tune in." Rather, they are engaged in molecular interchange that is framed in terms of human speech as autoinduction metaphors had done. Scripps Health, to take a similar example, also emphasizes the deafening roar of microbiome conversation: "The gut is colonized by around 100 trillion microbes—including thousands of different bacterial, fungal and viral species—that play a critical role in this constant chatter." The biology of bacterial "chatter" is not the same as gut-brain signaling, but it seems important to these and other authors to emphasize that the gut is a lively place populated by organisms who are conversational by nature. QS and other forms of microbial communication enable an easy transition to describing microbes as talking with the brain, in an extension of the conversations in which they are already engaged.

The same tropes recur more forcefully when discussing interchange between the microbiome, gut, and brain as a conversation. *Science News for Students* reports on GBMA research using the same sorts of conversational metaphors that drove QS-sociality metaphors. Author

Bethany Brookshire describes the "ongoing conversation taking place between the brain and gut" as a form of "chatter," in which our brain "can talk back," in a sequence of "chemical text-messages" going back and forth. The messaging is constant: "the brain and gut send constant cascades of notes back and forth, more than any social media." Thanks to diet, she concludes, our microbes can be encouraged to "carry on cozy chats with your brain." The theme recurs widely. Nutraingredients, a news site reporting on the science of nutritional supplements, describes this phenomenon as "gut-brain gossip" (Chu). And UW Medicine suggests that "you're having little conversations with yourself all day long … Your belly and your brain talk to one another constantly" (Domonell). Likewise, science journalist Cassandra Willyard quotes Cryan to suggest the vagus nerve connecting brain and gut to be "really a highway"; she adds that the nerve "has a crucial role in ferrying messages between the gut and brain."

This constant conversation presents a rather narrow role for the brain, however, casting it as the almost passive recipient of the conversations going on below. The reception and sending of messages along the vagus highway is not something that humans can control or interpret innately; it happens non-cognitively as a physiological process unfolding without interpretation. In this sense, it resembles the limitations of QS and science fiction discussed above, presenting bacteria as busily conversant yet only within their own realm, paradoxically social and harmonious.

Except that, as in Slonczewski's fiction, the possibility for translation and conversation *does* exist. Where QS discourse once short-circuited by reverting to decoding references when considering humans in relation to conversational bacteria, in GBMA discourse is evident a broader potential for conversation. Especially in regards to psychobiotics, humans are suggested to be capable of talking back; they are granted agency as conversational partners. An article by biochemist Sebastian Wellford in *Medium* presents QS and other aspects of microbiome as an act of "learning to

speak Germ-man." And *Psychobiotic Revolution* pervasively suggests that consuming foods or therapeutics for the purpose of altering the microbiome can be understood as a human speech act—we are "learning the language of the microbes." The book is premised on the possibility of learning to "talk back" and "reassert control" over our microbes. They promise that through the use of psychobiotics, you can "change the composition of your gut," steering the conversation in whichever way you choose. Cryan suggests that "unlike your genome, which you can't do much about … your microbiome is potentially modifiable. And that gives great agency to patients" (Willyard). Eating and pharmaceuticals, in other words, are an act of translation in which we eat in order to influence a dialogue unfolding inside the human body. This is a conversation that is not merely passive. Rather, it is a conscious act of consumption by humans actively expressing their desires for health, weight loss, or emotional wellbeing.

In physician Raphael Kellman's book *The Microbiome Diet,* the possibility of grasping control over our microbes is framed as a communicative interchange between two intelligences. Capturing the conversational tropes mentioned above, he suggests that "your brain talks to your gut and your microbiome – and listens to them, too!" (125). Such conversations presumably ensure the smooth functioning of human body and mind, influencing both health and mood. Tapping into the conversation, through diet, is a means of "reconnect[ing] to the collective intelligence of your microbiome," of "listen[ing] to your body and hear[ing] what it needs" (156). For Kellman, the act of listening to one's body enables a form of connection, the happy reunion of body, mind, and gut. He frames this as a collective endeavor, in which "trillions of microorganisms within your brain, gut, and cells are ready to help you succeed—if you only give them the nourishment they need." Healthy microbes, healthy humans, joined through dietary intervention in a single conversational loop.

The trope is given visual form in a recurring image, versions of which exist across GBMA popular science writing. Namely, the depiction of cartoon microbes busily engaged in chatter with human organs. An instance from *Chemical & Engineering News*, for example, shows brain and intestines linked by wires (Figure 33)(Howes). This conversation takes shape as a sequence of auditory speech acts. Four colorful bacteria chirp up, hollering between themselves ("?!?!" "!!!") while one spokes-bacterium directs speech waves toward the brain. The brain is drawn with a series of whiskers indicating noise impacting on its surface. Message received!

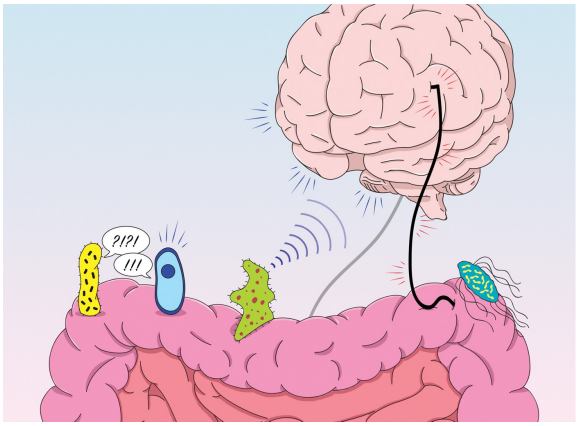

Figure 33. Gut-brain conversation as figured in Chemical & Engineering News *(Howes).*

Sometimes this extends as far as actual vocalization. In *Psychobiotic Revolution,* the authors repeatedly describe talk therapy as a potential tool for influencing the conversation you are having with your microbiome. Citing a benefit for patients with gut disorders who undergo cognitive behavioral therapy, they even suggest that you can *talk out loud* to your microbiome:

> You could help people just by talking with them and engaging their minds. Why does talk help? … As we learn more about the gut-brain axis, we realize that it's a two-way street. Gut issues can affect the brain, but the brain can also affect the gut. So one might say that talk therapy ultimately is a conversation between the therapist and the gut microbiota.

Conversing, out loud, with your microbiota! Surely this is the pinnacle of the human-bacterial interactivity conceit that has been building since the 1960s. And although this idea is clearly far-fetched, it does underscore an important shift in microbiome discourse, serving as a functional corrective to the problem of the receding human. Where once knowledge of our vast microbiome caused the human body to recede from view, now we are starting to bring ourselves, bodies and minds, back into the picture. It's an argument that we are more than a vehicle for microorganisms, and that we can learn to live with them in ways that consider our own agency, and which at last bring humans and microbes together as conversational and biological partners.

5. Conclusions

In GBMA popular science writing, modern life is no longer so hopeless as it appeared early in the microbiome era. While in the texts discussed above bubble kids and germfree animals still populate the discursive landscape, they are less potent as symbols of humanity's fate. The human microbiome has become something more flexible, less bound to the normative ideal of ancestral microbiomes and to the performance of probiotic maintenance duties. GBMA discourse recognizes implicitly that the microbiota are not *disappearing* but may in fact be nurtured back into healthy proportion, shaped to refine an individual's health even in the face of modern life's antibiotic threats.

While it is certainly true that this area of research is sensationalized across journalism and the media as much as the early wave of microbiomania, and while situating the power to manipulate the microbiome in pharmaceutical production certainly creates worrisome regulatory issues, it nevertheless valuably uncouples microbiome from identity. In the GBMA framework, humans are less fully defined by the microbes that "make us who we are," instead becoming active agents in the

restoration of a healthier body. Further, acts of intervention are not mandatory—save the microbiome now before it disappears! before your newborn grows into their dysbiotic nightmare future!—but more open-ended, more open to individual preference. Health now becomes a thing to discuss with one's microbes, through listening and attending to the parties within, rather than an action to force down from the top. Even among the depletions of modern life, the microbiome continues to rescue us; the microbes that once seemed to wield control come back to us as collaborators. In recognizing the parliamentary nature of bacteria, we come closer to integration than was possible before, through participating in acts of dialogue and mutual respect even as we continue to recognize microbes for their breathtaking diversity and creative power.

Works Cited

"After the Integrative Human Microbiome Project, What's next for the Microbiome Community?" *Nature*, vol. 569, no. 7758, May 2019, pp. 599–599. *D*

Alagarasan, Ganesh, and Kumar S. Aswathy. "Shoot the Message, Not the Messenger—Combating Pathogenic Virulence in Plants by Inhibiting Quorum Sensing Mediated Signaling Molecules." *Frontiers in Plant Science*, vol. 8, no. Article 556, Apr. 2017.

Anderson, Scott C., et al. The Psychobiotic Revolution: Mood, Food, and the New Science of the Gut-Brain Connection. National Geographic, 2017.

Bassler, Bonnie L. "How Bacteria Talk to Each Other: Regulation of Gene Expression by Quorum Sensing." *Current Opinion in Microbiology*, vol. 2, 1999, pp. 582–87.

---. "Microbes as Menaces, Mates & Marvels." *Dædalus, the Journal of the American Academy of Arts & Sciences*, vol. 141, no. 3, Summer 2012, pp. 67–76.

---. "Small Talk: Cell-to-Cell Communication in Bacteria." *Cell*, vol. 109, May 2002, pp. 421–24.

Bear, Greg. *Blood Music*. Orion Publishing Group, 1985.

---. "Blood Music." The Collected Stories of Greg Bear, Tor, 2002.

Belling, Catherine Francis. "Microbiography and Resistance in the Human Culture Medium." *Literature and Medicine*, vol. 22, no. 1, Spring 2003, pp. 84–101.

Bencard, Adam, and Louise Emma Whiteley. "*Mind the Gut* —Displaying Microbiome Research through Artistic Collaboration." *Microbial Ecology in Health and Disease*, vol. 29, no. 2, Nov. 2018, p. 1555433.

Brameyer, Sophie, et al. "Languages and Dialects: Bacterial Communication beyond Homoserine Lactones." *TRENDS in Microbiology*, vol. 23, no. 9, Sept. 2015, pp. 521–23.

Brookshire, Bethany. "Belly Bacteria Can Shape Mood and Behavior." *Science News for Students*, 7 June 2018, https://www.sciencenewsforstudents.org/article/belly-bacteria-can-shape-mood-and-behavior.

Cheyne, Ria. "Created Languages in Science Fiction." *Science Fiction Studies*, vol. 35, no. 3, Nov. 2008, pp. 386–403.

Chu, Will. "Gut-Brain Axis Uses Immune System to 'Talk,' Study Shows." *Nutraingredients*, 23 May 2016, https://www.nutraingredients.com/Article/2016/05/23/Gut-brain-axis-uses-immune-system-to-talk-study-shows.

Couvreur, André. "An Invasion of Macrobes." *The Exploits of Professor Tornada: Volume 1*, translated by Brian Stableford, Black Coat Press, 2014.

Domonell, Kristen. "The Gut-Brain Axis: How Bacteria in Your Belly Are Messing With Your Mind." *Right as Rain by UW Medicine*, 30 Aug. 2017, https://rightasrain.uwmedicine.org/body/gut-brain-axis-gut-microbiome.

Dougherty, Stephen. "Radio, The Genome, and Greg Bear's Biological Fiction." *Science Fiction Studies*, vol. 44, no. 1, Mar. 2017, pp. 104–21.

Dunny, Gary M., and Stephen C. Winans. "Bacterial Life: Neither Lonely nor Boring." *Cell-Cell Signaling in Bacteria*, ASM Press, 1999, pp. 1–5.

Dutton, Patrick. "The Beautiful Bacillus." *Amazing Stories*, vol. 6, no. 3, June 1931, pp. 262–72.

Engebrecht, JoAnne, and Michael Silverman. "Nucleotide Sequence of the Regulatory Locus Controlling Expression of Bacterial Genes for Bioluminescence." *Nucleic Acids Research*, vol. 15, no. 24, 1987, pp. 10455–67.

England, R. R., et al. "Editors' Preface." Microbial Signalling and Communication: Fifty-Seventh Symposium of the Society for General Microbiology Held at the University of Edinburgh April 1999, Cambridge University Press, 1999, pp. xi–xiv.

Fasano, Alessio, and Susie Flaherty. *Gut Feelings: The Microbiome and Our Health*. The MIT Press, 2021.

Fearn, John Russell. "Dynasty of the Small." *Dynasty of the Small*, Wildside Press LLC, 2012, pp. 1–54.

Federle, Michael J., and Donald A. Morrison. "One If by Land, Two If by Sea: Signalling to the Ranks with CSP and XIP." *Molecular Microbiology*, vol. 86, no. 2, Oct. 2012, pp. 241–45.

Fishel, Stefanie. The Microbial State: Global Thriving and the Body Politic. University of Minnesota Press, 2017.

Foster, Jane A., and Karen-Anne McVey Neufeld. "Gut–Brain Axis: How the Microbiome Influences Anxiety and Depression." *Trends in Neurosciences*, vol. 36, no. 5, May 2013, pp. 305–12.

Fox, Tyler S. *Fermentum Gallery*. http://www.tylersfox.com/#/fermentum-gallery/. Accessed 1 July 2021.

Fuqua, Clay, et al. "Census and Consensus in Bacterial Ecosystems: The LuxR-LuxI Family of Quorum-Sensing Transcriptional Regulators." *Annual Review of Microbiology*, vol. 50, 1996, pp. 727–51.

Gray, Kendall M. "Intercellular Communication and Group Behavior in Bacteria." *TRENDS in Microbiology*, vol. 5, no. 5, May 1997, pp. 184–88.

Henke, Jennifer M., and Bonnie L. Bassler. "Bacterial Social Engagements." *TRENDS in Cell Biology*, vol. 14, no. 11, Nov. 2004, pp. 648–56.

Hense, Burkhard A., et al. "Does Efficiency Sensing Unify Diffusion and Quorum Sensing?" *Nature Reviews Microbiology*, vol. 5, Mar. 2007, pp. 230–39.

Howes, Laura. "How Your Gut Might Modify Your Mind." *Chemical & Engineering News*, 8 Apr. 2019, https://cen.acs.org/biological-chemistry/microbiome/gut-might-modify-mind/97/i14.

Hustak, Carla, and Natasha Myers. "Involutionary Momentum: Affective Ecologies and the Sciences of Plant/Insect Encounters." *Differences*, vol. 23, no. 3, 2012, pp. 74–118.

Jacob, François. *The Logic of Life: A History of Heredity*. Princeton University Press, 1993.

Jakubovics, N. S. "Talk of the Town: Interspecies Communication in Oral Biofilms." *Molecular Oral Microbiology*, vol. 25, 2010, pp. 4–14.

Joint, Ian, et al. "Bacterial Conversations: Talking, Listening and Eavesdropping. An Introduction." *Philosophical Transactions of the Royal Society B*, vol. 362, 2007, pp. 1115–17.

Joshi, Priyanka, et al. "Microbial Chit-Chat: Quorum Sensing." *The IUP Journal of Life Sciences*, vol. IV, no. I, 2010, pp. 58–72.

Kaiser, Dale. "Bacteria Also Vote." *Science*, vol. 272, no. 5268, June 1996, pp. 1598–99.

Kaiser, Dale, and Richard Losick. "How and Why Bacteria Talk to Each Other." *Cell*, vol. 73, June 1993, pp. 873–85.

Kellman, Raphael. The Microbiome Diet: The Scientifically Proven Way to Restore Your Gut Health and Achieve Permanent Weight Loss. First Da Capo Press edition, Da Capo Lifelong Books, 2014.

Kolter, Roberto, and Losick, Richard. "One for All and All for One." *Science*, vol. 280, no. 5361, Apr. 1998, pp. 226–27.

Larson, Brendon. Metaphors for Environmental Sustainability: Redefining Our Relationship with Nature. Yale UP, 2011.

Lyon, Pamela. "From Quorum to Cooperation: Lessons from Bacterial Sociality for Evolutionary Theory." *Studies in History and Philosophy of Biological and Biomedical Sciences*, vol. 38, 2007, pp. 820–33.

Martin, Emily. "Toward an Anthropology of Immunology: The Body as Nation-State." *Medical Anthropology Quarterly*, vol. 4, no. 4, Dec. 1990, pp. 410–26.

Mayer, Emeran A., et al. "Brain–Gut Microbiome Interactions and Functional Bowel Disorders." *Gastroenterology*, vol. 146, no. 6, May 2014, pp. 1500–12.

Meyers, Walter E. *Aliens and Linguists: Language Study and Science Fiction*. The University of Georgia Press, 1980.

Michie, Kelly L., et al. "Bacterial Tweets and Podcasts #signaling#eavesdropping#microbialfightclub." *Molecular & Biochemical Parasitology*, vol. 208, 2016, pp. 41–48.

Milburn, Colin. "Nanotechnology." *The Routledge Companion to Literature and Science*, Routledge, 2011, pp. 181–91.

Nealson, Kenneth H. "Autoinduction of Bacterial Luciferase: Occurrence, Mechanism and Significance." *Archives of Microbiology*, vol. 112, 1977, pp. 73–79.

---. "Cellular Control of the Synthesis and Activity of the Bacterial Luminescent System." *Journal of Bacteriology*, vol. 104, no. 1, Oct. 1970, pp. 313–22.

---. "Early Observations Defining Quorum-Dependent Gene Expression." *Cell-Cell Signaling in Bacteria*, edited by Gary M. Dunny and Stephen C. Winans, ASM Press, 1999, pp. 277–90.

O'Mahony, S. M., et al. "Serotonin, Tryptophan Metabolism and the Brain-Gut-Microbiome Axis." *Behavioural Brain Research*, vol. 277, Jan. 2015, pp. 32–48.

Otis, Laura. Membranes: Metaphors of Invasion in Nineteenth-Century Literature, Science, and Politics. The Johns Hopkins University Press, 1999.

Parrinder, Patrick. "The Alien Encounter: Or, Ms Brown and Mrs Le Guin." *Science Fiction Studies*, vol. 6, no. 1, Mar. 1979, https://www.depauw.edu/sfs/backissues/17/parrinder17.htm.

Proctor, Lita. "Priorities for the next 10 Years of Human Microbiome Research." *Nature*, vol. 569, no. 7758, May 2019, pp. 623–25.

"Quorum, n." *Oxford English Dictionary*, 3rd ed., June 2008, http://www.oed.com.

Redfield, Rosemary J. "Is Quorum Sensing a Side Effect of Diffusion Sensing?" *TRENDS in Microbiology*, vol. 10, no. 8, Aug. 2002, pp. 365–70.

Reynolds, Andrew. "Ernst Haeckel and the Theory of the Cell State: Remarks on the History of a Bio-Political Metaphor." *History of Science*, vol. 46, no. 2, 2008, pp. 123–52.

Robert III, Henry M., et al. *Robert's Rules of Order Newly Revised*. 11th ed., Da Capo Press, 2011.

Roosth, Sophia. "Screaming Yeast: Sonocytology, Cytoplasmic Milieus, and Cellular Subjectivities." *Critical Survey*, vol. 35, no. 2, 2009, pp. 332–50.

Sifri, Costi D. "Quorum Sensing: Bacteria Talk Sense." *Healthcare Epidemiology*, vol. 47, 2008, pp. 1070–76.

Slonczewski, Joan. "Bacteria Tell Us What to Eat." *Ultraphyte*, 24 Aug. 2014, https://ultraphyte.com/2014/08/24/bacteria-tell-us-what-to-eat/.

---. *Brain Plague*. Phoenix Pick, 2000.

---. *The Children Star*. Phoenix Pick, 1998.

The Constitution of the United States: Article 1, Section 2. http://constitutionus.com/.

Tuckey, John S., editor. "Three Thousand Years Among the Microbes." *Mark Twain's Which Was the Dream? And Other Symbolic Writings of the Later Years*, by Mark Twain, University of California Press, 2019, pp. 433–554.

Turovskiy, Yevgeniy, et al. "Quorum Sensing: Fact, Fiction, and Everything in Between." *Advances in Applied Microbiology*, vol. 62, 2007, pp. 191–234.

Visick, Karen L., and Clay Fuqua. "Decoding Microbial Chatter: Cell-Cell Communication in Bacteria." *Journal of Bacteriology*, vol. 187, no. 16, Aug. 2005, pp. 5507–19.

von Bodman, Susanne B., et al. "Cell-Cell Communication in Bacteria: United We Stand." *Journal of Bacteriology*, vol. 190, no. 13, July 2008, pp. 4377–91.

Weindling, Paul. "Theories of the Cell State in Imperial Germany." *Biology, Medicine and Society 1840–1940*, edited by Charles Webster, Cambridge University Press, 1981, pp. 99–156.

Wellford, Sebastian. "The Microbiota: Learning to Speak Germ-Man." *Medium*, 9 Jan. 2016, https://medium.com/a-spoonful-of-sugar/the-microbiota-learning-to-speak-germ-man-9c41a66d120e\.

Willyard, Cassandra. "How Gut Microbes Could Drive Brain Disorders." *Nature*, vol. 590, no. 7844, Feb. 2021, pp. 22–25.

Winans, Stephen C. "Bacterial Esperanto." *Nature Structural Biology*, vol. 9, no. 2, Feb. 2002, pp. 83–84.

Winans, Stephen C., and Bonnie L. Bassler. "Mob Psychology." *Journal of Bacteriology*, vol. 184, no. 4, Feb. 2002, pp. 873–83.

Winzer, Klaus, et al. "Bacterial Cell-to-Cell Communication: Sorry, Can't Talk Now—Gone to Lunch!" *Current Opinion in Microbiology*, vol. 5, 2002, pp. 216–22.

Zimmer, Carl. "Our Microbiome May Be Looking Out for Itself." *The New York Times*, 14 Aug. 2014, https://www.nytimes.com/2014/08/14/science/our-microbiome-may-be-looking-out-for-itself.html.