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Public Health Approach to Improve Outcomes for Congenital Heart Disease Across the Life Span

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Congenital heart disease (CHD), which is present in around 1.0% (1 in 110) of all live births in the United States, is the most common birth defect.^{1–5} Defined generally as malformations present at birth that involve the heart or major associated blood vessels, CHD includes a remarkably heterogeneous group of chronic conditions, with very different phenotypes, prevalence, risk factors, and outcomes. CHD is a significant contributor to birth-defect–related morbidity, mortality, and healthcare costs⁶ in early life and increasingly among adolescents and adults.⁷ Because of their broad impact at the population level, a public health approach is needed to address the challenges of these common, critical, and costly conditions.⁸ We sought to create a framework to address CHD from a population-based perspective, to serve as a model for a public health agenda for the United States, with a goal of improving the lives of those with or at risk for CHD. This framework is complementary to previous work outlining the Centers for Disease Control and Prevention’s scientific priorities related to CHD,⁹ because implementation strategies are also needed in addition to addressing gaps in scientific knowledge.^{9–11}

The CHD framework is a public health model for addressing disease at the population level, which emphasizes monitoring, interventions, and optimizing outcomes at the population

level. Core components of a public health model are: (1) *identifying* or monitoring the occurrence and outcomes of a condition over time and among different subgroups in the population; (2) *investigating* factors that impact occurrence and outcomes, specifically causes of disease and modifiers of prognosis; (3) *developing* interventions and policies to reduce risks and improve outcomes; (4) *implementing* interventions and policies; and (5) *evaluating* the effectiveness of such interventions and policies.¹² These components are interconnected in that improvements in each component lead to improvements in the entire framework and success in addressing public health challenges.

The main features of the public health framework for CHD, presented in language appropriate for a lay audience, have three key pillars: *Identify and Investigate*, *Develop Interventions and Policies*, and *Implement and Evaluate* (Figure 1). The scope encompasses everyone at risk for CHD or living with CHD to underscore the need for equitable and universal access to care delivery and services. In the following sections, components are discussed, along with key issues identified by the Congenital Heart Public Health Consortium (CHPHC) for improved outcomes. Key opportunities to advance a public health agenda for CHD are listed (Table 1).

Identify and Investigate

Identification includes monitoring both prevalence and outcomes—CHD prevalence at birth and across the life span as well as survival, morbidity, and disability. At any age, prevalence depends on both birth prevalence and survival. Disparities in survival based on race or ethnicity, or associated factors such as socioeconomic status or parental education, impact the prevalence of specific types of CHD at different ages.¹³ Reliable population-based monitoring of CHD requires several elements: operational case definitions that are clear and consistent; a source population that is well defined in time and space; and a sustainable ascertainment system of CHD occurrence and outcomes that is accurate, complete, and timely. In the United States, there are

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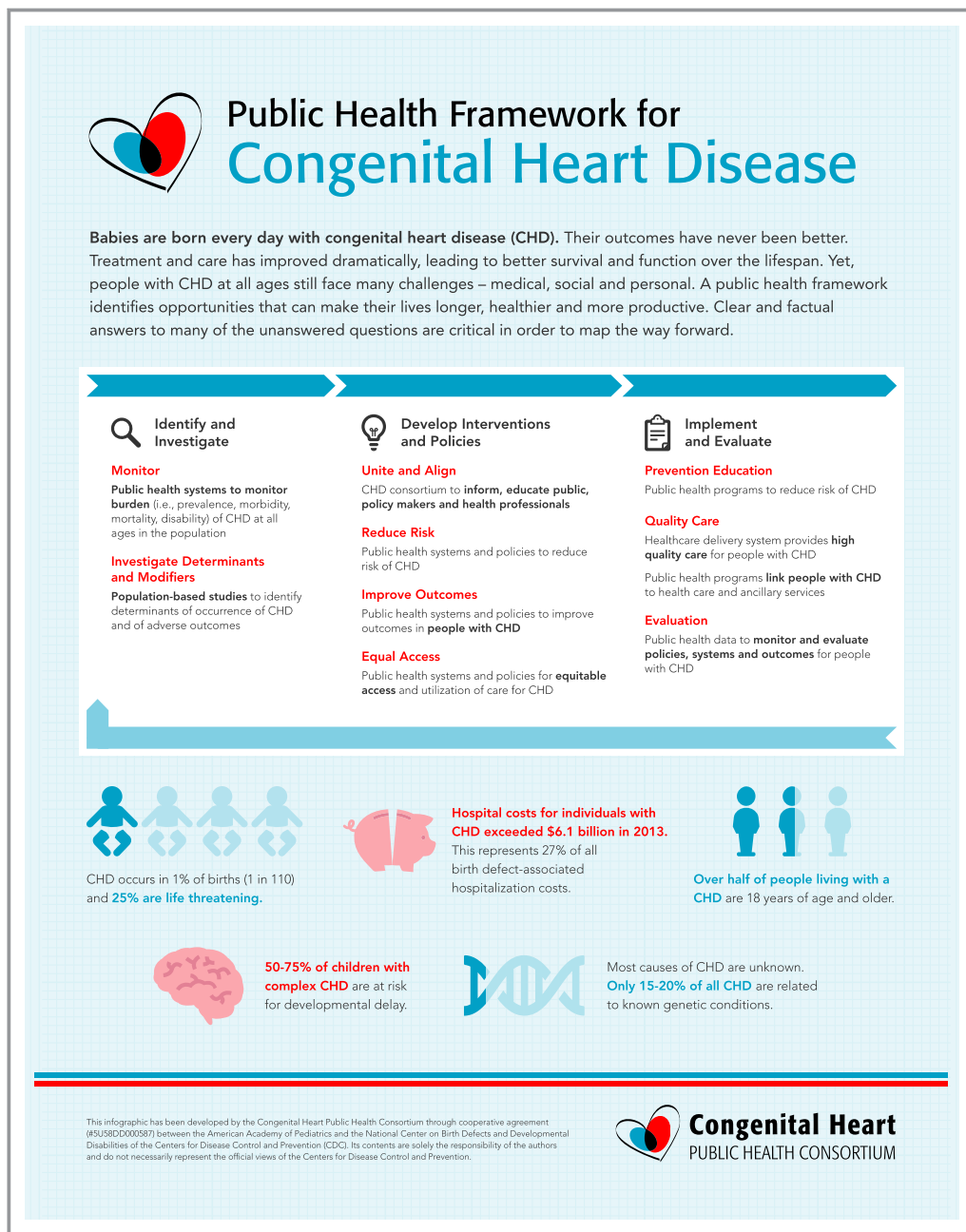


Figure 1. Congenital heart public health consortium public health framework for congenital heart disease.

well-established programs for monitoring CHD at birth. The National Birth Defects Prevention Network has provided guidance for monitoring 16 specific types of CHD among births.¹⁴ In contrast, population-based monitoring of CHD beyond infancy and childhood nationwide is much less developed and has significant gaps.¹⁵ These gaps pose a major challenge for population-based public health programs aimed at addressing the needs of people with CHD across the life span. A fragmented system of care for those with CHD contributes to this challenge, particularly for adults. The

situation in the United States is in contrast to a few successful models of population-based monitoring of CHD throughout the life span.^{16,17}

Investigation includes epidemiological research to understand key elements such as: (1) factors that increase or decrease the risk of developing CHD and (2) factors, including genetic factors, that modify outcomes in those born with CHD, including survival, health, quality of life, societal integration, and other long-term outcomes, such as neurodevelopmental and psychosocial outcomes and reproductive health. Currently,

Table 1. Key Opportunities to Advance Public Health for Individuals With Congenital Heart Disease

Identify and Investigate	
	Monitor
1	Initiate comprehensive population-based monitoring of the incidence, prevalence, morbidity and mortality of congenital heart defects across the life span
	Investigate determinants and modifiers
2	Leverage existing data to examine epidemiological and clinical factors associated with better and worse health outcomes health service delivery
Develop Interventions and Policies	
	Unite and align
3	Design universally accepted policies and interventions to improve access to appropriate care, including specialty care and services
	Reduce risk
4	Identify optimum timing of type of procedural medical intervention to inform treatment decisions in infancy, childhood, and adulthood
5	Research to identify strategies to reduce cardiac and noncardiac morbidity, including the brain, lungs, liver, and kidneys
6	Initiate practical, effective, and sustainable interventions for known modifiable risk factors for congenital heart disease that have public health importance (eg, maternal pregestational diabetes mellitus)
	Improve outcomes
7	Improve access to special education and/or other school-based interventions for all children with congenital heart disease who have a neurodevelopmental impairment
8	Develop formal transition programs between pediatric and adult care and ongoing monitoring to assess the success or obstacles to transition efforts
9	Initiate programs to assure adequate support services for adults with neurocognitive decline
	Equal access
10	Encourage insurance availability for congenital heart disease care across the life span, including specialty care when necessary
11	Develop programs to assure that all people with congenital heart disease have primary care in a patient-centered medical home that includes supports to family members and caregivers
Implement and Evaluate	
	Prevention education
12	Target educational programs to individuals and the medical community to disseminate information about proven and effective strategies to prevent congenital heart disease
	Quality care
13	Project workforce necessary to care for the growing population of adults with congenital heart disease and adjust the number of fellowship training programs and positions accordingly
14	Optimize healthcare systems with adequate specialty care for cardiac and noncardiac conditions to address the needs of people with congenital heart disease
	Evaluation
15	Develop and track key quality measures related to care for congenital heart disease and congenital heart disease–related population health

most causes of CHD are not known. A large fraction of CHD is thought to have a multifactorial etiology—that is, many cases are thought to be caused by a variable and mostly undetermined combination of environmental and genetic factors.^{18,19} Determining the nature and contribution of these factors to the risk of developing CHD has proven remarkably difficult. Nevertheless, such research is crucial to design evidence-based interventions aimed at primary prevention (reducing the number of newborn cases of CHD)⁹ and secondary prevention (reducing

complications and improving outcomes for the many infants who continue to be born with CHD).²⁰ The population of adolescents and adults with CHD continues to grow rapidly, underscoring a need to investigate modifiable population-level factors that can be leveraged to improve outcomes across the life span. Recent evidence suggests ongoing risk for early mortality, even after repair of less-severe CHD lesions.⁷ Multiple data sets are available and potentially useful to examine CHD outcomes and health services utilization.²¹

Key Issues Related to Monitoring

1. Infants with CHD are at increased risk for morbidity, mortality, and developmental disabilities not only in infancy, but also for decades later.^{13,22,23}
2. Children and adults with CHD can develop problems in numerous other organ systems, most notably the neurological,^{23–26} pulmonary,²⁷ renal,²⁸ gastrointestinal,²⁹ and hematologic/oncological³⁰ systems. Adults with complex CHD are at risk for lower functioning, achievement, executive function, memory, language, social interactions, and quality of life.³¹ Risk factors for brain injury are cumulative and synergistic.^{32,33}
3. There is no nation-wide system for monitoring the number and health of people living with CHD.
4. There is no system to monitor outcomes of offspring of people with CHD, or to monitor the outcomes of pregnancies among women with CHD.
5. Limited information is available regarding racial, ethnic, and socioeconomic characteristics of people living with CHD.

Key Issues Related to Investigating Determinants and Modifiers

Primary Prevention

1. Nongenetic factors have been linked to increased risk for CHD, including maternal conditions such as uncontrolled pregestational diabetes, and pregnancy exposures, such as some infections and medications.^{18,34–36} As a group, however, recognized environmental or maternal risk factors still account for a small fraction, likely $\leq 10\%$, of nonsyndromic CHD in the population.^{35–36} Most women who give birth to children with CHD do not have or report exposures to known risk factors; even among those who report such exposures, the causal role of the exposure can be difficult to establish in any individual case.
2. Prenatal exposure to prescription opioids has been linked to risk of some types of CHD,³⁷ in addition to the well-documented causal relationship with neonatal abstinence syndrome. This type of risk factor with growing levels of prenatal exposure merits additional research to better understand the prevalence, timing, and correlates of prenatal exposure linked to greatest risk for infants.
3. The proportion of CHD cases attributed to genetic causes—chromosomal anomalies, genomic disorders (deletions or duplications), and single-gene conditions—is still unclear. Chromosomal anomalies alone seem to account for $\approx 10\%$ to 15% of cases of congenital heart defects.^{38,39} The risk of some of these chromosomal anomalies (eg, trisomy 21, 18, and 13) are influenced by maternal age. As a group, single-gene disorders (eg, the Noonan, Alagille,

and CHARGE syndromes) probably account for a much smaller fraction of cases.³⁸ However, recent findings using more-advanced technology suggest that de novo mutations and novel copy number variants may account for an additional 10% to 15% of incident cases.^{40–42} What remains largely unclear is to what extent genetic loci contribute to disease risk and, in particular, to gene-environment interactions that are modifiable by preventive interventions.

Secondary Prevention

1. Appropriate timing for repeat interventional procedures is not well established. Timing is important given that delayed repair may lead to sequelae such as irreversible myocardial dysfunction and arrhythmia. Conversely, procedures with limited durability may result in the need for additional procedures over the life span.
2. Emerging data suggest that older individuals with CHD are at increased risk for mortality, driven by coronary artery disease, heart failure, and ventricular dysfunction.⁴³
3. Risk for coronary artery disease is related to age, hyperlipidemia, and hypertension.⁴⁴ Certain types of CHD, such as coarctation of the aorta, may increase the risk for hypertension. Exercise restrictions may increase the risk for obesity. Little is known about how to prevent or treat acquired heart disease in people with CHD.

Develop Interventions and Policies

Public health interventions and policies that focus on CHD can improve the health and well-being of people with CHD. Uniting and aligning efforts among stakeholders should accelerate effectively addressing CHD from a public health perspective. The CHPHC was formed in 2009 as an organization of stakeholders utilizing public health principles to affect change for those with CHD at the population level (<http://www.chphc.org>).^{10,11} The CHPHC has over 200 members, including individuals and organizations, as well as liaisons from key federal agencies (Table 2). The activities of the CHPHC are coordinated by the American Academy of Pediatrics, with support from the Centers for Disease Control and Prevention. Since inception, the CHPHC has accomplished multiple initiatives, such as assembling information to disseminate key facts, identifying databases available for CHD surveillance and research, and public awareness campaigns on various topics related to CHD. The CHPHC can play a key role in aligning efforts to advance a public health agenda to improve lives for those affected by CHD.

To date, there are few specific policies or interventions designed to reduce the impact of CHD on the US population.

An exception is the implementation of newborn screening using pulse oximetry to detect critical CHD at birth and decrease infant mortality resulting from undiagnosed CHD. Fortification of cereals with folic acid, although aimed at preventing other birth defects (ie, neural tube defects), may prevent some CHD.¹⁸ Because of the many gaps in current knowledge, more research—particularly translational research—is needed. However, several important opportunities for primary and secondary prevention of CHD are currently available based on what is already known about modifiable risk factors.

Key Issues Related to Uniting and Aligning

1. Stakeholders interested in improving CHD outcomes across the life span often work independently, without alignment.

Key Issues Related to Reducing Risk

1. Known modifiable risk factors for CHD include pregestational diabetes without adequate control, uncontrolled maternal phenylketonuria, and maternal pregnancy exposures, such as infections and the use of certain medications, continue to occur.

Table 2. Congenital Heart Public Health Consortium Steering Committee Member Organizations and Federal Liaisons

Steering Committee Members	Federal Liaisons
Adult Congenital Heart Association	Centers for Disease Control and Prevention
Alliance for Adult Research in Congenital Cardiology	National Center on Birth Defects and Developmental Disabilities
American Academy of Pediatrics	National Institutes of Health
Section on Cardiology and Cardiac Surgery	National Heart, Lung, and Blood Institute
American College of Cardiology	Agency for Healthcare Research and Quality
Adult Congenital & Pediatric Cardiology Section	Center for Quality Improvement and Patient Safety
American Heart Association	Health Resources and Services Administration
Cardiovascular Disease in the Young	
Children’s Heart Foundation	
Congenital Heart Surgeon’s Society	
National Birth Defects Prevention Network	
Mended Little Hearts	
March of Dimes (2009–2017)	
Pediatric Congenital Heart Association	
Society for Thoracic Surgeons	

Key Issues Related to Improving Outcomes

1. Many children with CHD have difficulties in cognition, language development, visual construction and perception, visual motor integration, executive function, attention, impulsivity, and fine and gross motor skills.²³ Poor executive functioning is closely associated with lower quality of life and school functioning in the CHD school-aged population.⁴⁵ Unrecognized or untreated neurodevelopmental impairments may lead to lower quality of life for children with CHD.^{25,46,47}
2. Children with CHD, particularly those with more-severe forms, can be screened for neurodevelopmental impairments.²³
3. Adults with CHD also have altered cognition and neuropsychological and neurological impairments⁴⁸ that can impact quality of life and workplace success.
4. Many adolescents and adults with CHD are not receiving specialty care.^{49,50}

Key Issues Related to Equal Access

1. Lack of healthcare providers with expertise in CHD, including cardiologists and cardiac surgeons, can preclude access, particularly in rural areas, or other geographical locations.
2. Insurance barriers can preclude access to necessary care for CHD, even when such care is available.
3. Unequal access to healthcare information related to CHD care may cause individuals or families to not seek appropriate care.

Implement and Evaluate

The measure of success of the public health approach aimed at improving both primary and secondary prevention is the extent to which it realizes a major reduction in the health impact of CHD in the entire population. While acknowledging that more research is needed, it is also important to develop and implement solutions based on what is already known. For example, maternal pregestational diabetes mellitus is an established risk factor for CHD,^{51–53} and primary prevention targeting diabetes mellitus before conception is possible today.^{54–56} It is also well established that diabetic women who are in optimal glycemic control immediately before and during pregnancy can reduce their risk of having a baby with CHD to nearly the level of those without pregestational diabetes mellitus.^{51,54,55} More concerted efforts could be undertaken to target screening and management of diabetes mellitus among childbearing-aged women at high risk of diabetes mellitus, with

implementation of both individual- and population-level interventions. These efforts would include increasing awareness among childbearing-aged women and healthcare providers about the risk of CHD associated with pregestational diabetes mellitus, as well as improving access to screening and care for diabetes mellitus to increase the proportion of childbearing-aged women with pregestational diabetes mellitus in optimal glycemic control. Modeling has estimated that ≈ 2670 congenital heart defects could be prevented annually in the United States if interventions succeeded in ensuring all women with pregestational diabetes mellitus were in optimal glycemic control immediately before and during pregnancy.⁵²

Similarly, secondary prevention should include comprehensive strategies with policy changes that improve access to specialty care across the life span, such as individual-level education of cardiologists and patients regarding the importance of life-long specialty care. Programs to improve secondary outcomes may target specific populations, such as implementation of neurodevelopmental screening for all children with CHD, as well as neurocognitive care and preventive care for adult patients as they age.³²

Evaluation is instrumental in demonstrating program effectiveness and allowing effective pilot intervention programs to be expanded to reach a broader population. For example, newborn screening based on pulse oximetry for critical CHD in the United States began in 2011, and, as of 2015, 43 states had taken steps toward implementing universal screening.⁵⁷ The goal of critical CHD screening is to reduce morbidity and mortality associated with delayed diagnoses, and evaluation will be essential in quantifying the impact of this public health intervention. Similarly, screening children and adults with CHD for neurodevelopmental/neurocognitive and psychosocial issues will provide secondary prevention opportunities to reduce the health impact of CHD on individuals over their entire life span through appropriate therapeutic interventions.^{23,32,33,48,58}

Key Issues Related to Prevention Education

1. Few educational programs exist that are targeted to individuals and the medical community about reasonable strategies to prevent CHD, based on current knowledge.

Key Issues Related to Quality Care

1. Appropriately treating the medical and nonmedical needs of children with CHD is difficult. For providers, creating a patient-centered medical home for children with CHD, particularly those with complex disease, is particularly

important.⁵⁹ For families, the toll on parents and siblings can be burdensome.⁶⁰

2. People with CHD begin to leave specialty care around age 8 years, over half are lost to follow-up by age 18 years,^{61,62} and >40% of adult CHD patients note a prolonged gap in cardiology care, typically around age 19 to 20 years^{50,63}; those with gaps in care are more likely to have adverse outcomes.^{64,65}
3. Transition of care from pediatric cardiologists to adult cardiologists with expertise in CHD is inconsistent, and the optimum transition practice is not known.
4. Accurate projections of the workforce needed to care for the growing population of adults with CHD are lacking.
5. As neurodevelopmental sequelae in children with CHD evolve to cognitive decline or dementia during adulthood, a growing population of individuals living with CHD may require support services.
6. The American Board of Internal Medicine and American Board of Pediatrics have recently established fellowships in adult CHD, with different pathways and a board examination. The Adult Congenital Heart Association is developing program accreditation standards and center accreditation is being piloted.

Summary and Recommendations

A public health framework is presented to guide a public health agenda for CHD in the United States. The framework includes: (1) *identification and investigation*, including public health monitoring systems and population-based research; (2) *development of interventions and policies*, including aligning stakeholders, creating public systems and policies to reduce risk, improving outcomes, and ensuring equitable access and utilization of care; and (3) *implementation and evaluation*, including education and quality care programs; connecting individuals, health care, and ancillary services; and evaluation of systems. The CHPHC aligns key stakeholders as a public-private partnership to reduce death and disability from CHD across the life span. Collective efforts within the framework by CHPHC members are addressing all components with improved coordination (Figure 2). Key opportunities to advance a public health agenda for CHD are listed in Table 1, including opportunities for research, monitoring, and implementation. The CHD population is growing, with significant risks, comorbidities, and enhanced need for healthcare resources. Knowledge gaps currently exist in many areas, and few policies and programs are specifically designed to reduce risk or improve outcomes for people with CHD. Future efforts aligned with the framework should accelerate knowledge and strategies to more rapidly reduce disease burden and improve outcomes at a population level for those affected by CHD.

PUBLIC HEALTH CALL TO ACTION

	Patient & Family				Clinical & Professional				Research		Federal Agency				Overall				
Identify and Investigate																			
Monitor					●				●		●				●	●	●	●	●
Investigate Determinants & Modifiers			●		●		●	●	●	●				●	●			●	●
Develop Interventions and Policies																			
Unite and Align		●	●	●	●	●				●	●	●			●				●
Reduce Risk		●			●		●				●	●			●	●			●
Improve Outcomes	●	●	●			●	●	●	●	●	●				●				●
Equal Access	●	●	●					●		●									●
Implement and Evaluate																			
Prevention Education	●	●				●	●					●			●				●
Quality Care	●		●			●	●		●	●	●								●
Evaluation			●	●	●					●				●	●	●			●



The Mission of the Congenital Heart Public Health Consortium is to prevent congenital heart defects and improve outcomes for affected children and adults.

The sample used for this table included the 12 national non-profit organizations and four federal agencies involved in the leadership of the Congenital Heart Public Health Consortium. The national non-profit organizations include Adult Congenital Heart Association, Alliance for Adult Research in Congenital Cardiology, American Academy of Pediatrics, American College of Cardiology, American Heart Association, Children’s Heart Foundation, Congenital Heart Surgeon’s Society, Mended Little Hearts, National Birth Defects Prevention Network, Pediatric Congenital Heart Association and Society for Thoracic Surgeons. Additional information about the Congenital Heart Public Health Consortium is available online at www.chphc.org.

Figure 2. Grid displaying CHPHC member activities related to public health framework call to action. CHPHC indicates Congenital Heart Public Health Consortium.

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Disclosures

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