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# Evaluation of Respiratory Emissions During Labor and Delivery

## *Potential Implications for Transmission of Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2)*

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**OBJECTIVE:** To characterize respiratory emissions produced during labor and vaginal delivery vis-à-vis the potential for transmission of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2).

**METHODS:** Observational study of three women who tested negative for SARS-CoV-2 and had uncomplicated vaginal deliveries. Using background-oriented schlieren imaging, we evaluated the propagation of respiratory emissions produced during the labor course and delivery. The primary outcome was the speed and propagation of breath over time, calculated through processed images collected throughout labor and delivery.

**RESULTS:** In early labor with regular breathing, the speed of the breath was 1.37 meters/s (range 1.20–1.55 meters/s). The breath appeared to propagate faster with a cough during early labor at a speed of 1.69 meters/s (range 1.22–2.27 meters/s). During the second stage of labor with Valsalva and forced expiration, the propagation speed was 1.79 meters/s (range 1.71–1.86 meters/s).

**CONCLUSION:** Labor and vaginal delivery increase the propagation of respiratory emissions that may increase risk of respiratory transmission of SARS-CoV-2.

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Person-to-person transmission of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) occurs mainly through direct contact or droplets containing the virus spread through respiratory emissions.[1,2] Aerosols are an additional suggested mode of transmission, because virus-containing particles travel further and remain suspended in air for longer.[3–5] However, there is limited consensus and evidence available to demonstrate which medical procedures should be classified as aerosol-generating.[6] Based on the available data, the Centers for Disease Control and Prevention (CDC) and the World Health Organization developed recommendations for use of personal protective equipment for health care workers and provided a list of aerosol-generating procedures in an attempt to mitigate the spread of the disease.[7,8]

Jackson et al[6] identified labor and delivery as a common procedure that was a likely suspected source of aerosolization, but the guidance on personal protective equipment use in this setting was sparce and only mentioned once in their systematic review of 128 documents. The aim of this study is to evaluate respiratory emissions during labor and delivery to provide data to guide recommendations for personal protective equipment use for obstetric practitioners.

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*Each author has confirmed compliance with the journal's requirements for authorship.*

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## METHODS

We present an observational study that is a characterization of respiratory emissions during the labor course and vaginal delivery of three women confirmed to be negative for SARS-CoV-2 infection who delivered at Ronald Reagan UCLA Medical Center. Institutional review board approval was obtained (UCLA IRB#20-000931), and the patients provided informed consent to be included within the study and for publication of this report. Using background-oriented schlieren imaging[9] involving a high-speed visible camera with a fixed-background dot pattern, we describe the density gradients in exhaled fluid flow during labor and delivery, noting the correlation between warm exhaled breath and the payload of pathogen-bearing droplets.[10] Imaging used a Sony Venice high-speed camera with an AXS-R7 external recording attachment, situated to the patient's left side at a distance of approximately 1.9 meters from the patient and oriented perpendicularly with respect to the patient's body. Visualization of the patient's breathing was accomplished with the camera and with a random background pattern placed on a cardboard at a distance of approximately 1.85 meters on the contralateral (right) side of the patient; the total distance between the camera and background was 3.75 meters. The general field of view in the imaging extended approximately 1.2 meters downstream from the patient's mouth and approximately 0.9 meters in the vertical direction, with the patient's body visible in the imaging (Fig. 1).

Labor and delivery rooms were maintained at a standard temperature and humidity condition that was considered comfortable for each patient. During recordings, care was taken to ensure the room was maintained at approximately 70° Fahrenheit to enable background-oriented schlieren imaging to visualize the difference in the warm breath produced relative

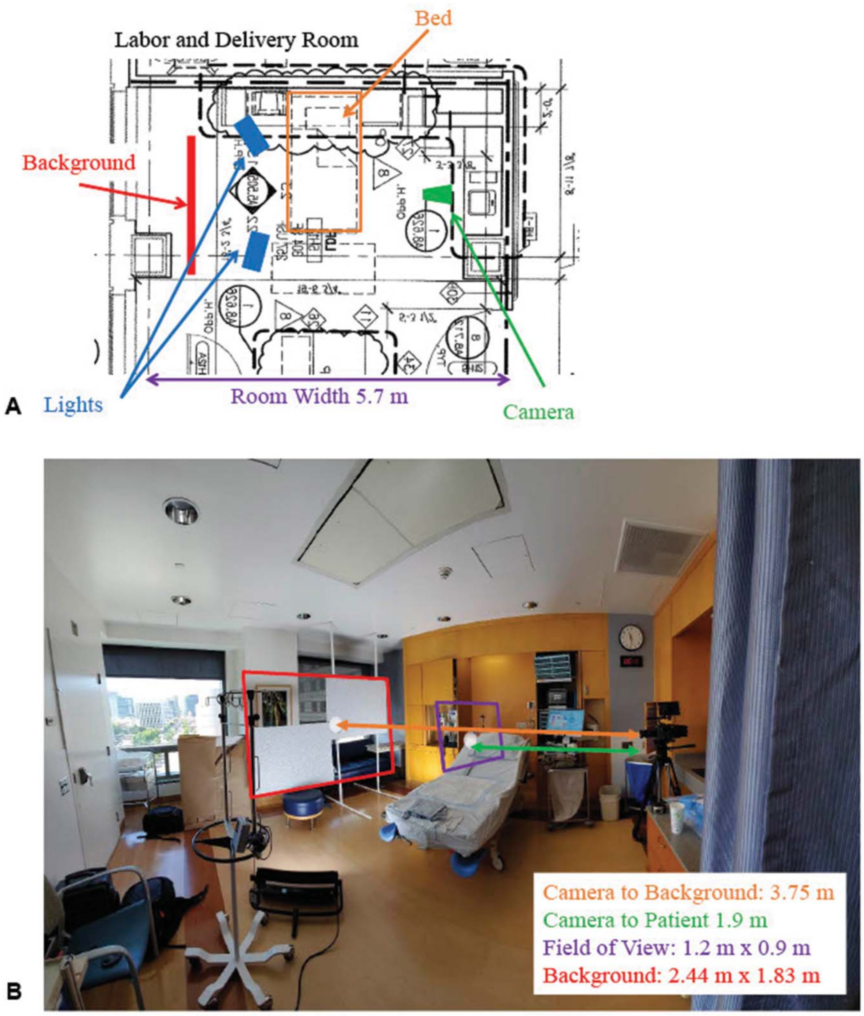


**Fig. 1.** Diagram (**A**) and photo depiction (**B**) of room setup for background-oriented schlieren imaging.

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**Table 1. Study Participant Characteristics**

| Patient | Age (y) | BMI (kg/m²) | Maternal Respiratory Disease | Gravidity | Parity | Indication for Delivery | Anesthesia | Gestational Age (wk) |
|---|---|---|---|---|---|---|---|---|
| 1 | 42 | 27.5 | No | 4 | 3 | Induction of labor for cholestasis of pregnancy | Regional | 39 1/7 |
| 2 | 22 | 24.6 | No | 1 | 0 | Labor | Regional | 39 0/7 |
| 3 | 35 | 41.7 | No | 2 | 1 | Induction of labor for poorly controlled gestational diabetes | Regional | 38 4/7 |

BMI, body mass index.

to the surroundings. Documented framing rates of 59.94 frames per second were employed, enabling 0.0167 seconds between each frame. There was a spatial resolution of 6,048 by 4,032 pixels, representing 6K resolution.

Recordings were obtained for each patient at three different respiratory conditions: early labor, when the patient was feeling minimal pain and breathing normally; early labor when the patient coughed; and in the second stage of labor when the patient was pushing followed by vaginal delivery. Imaging during additional stages of labor (eg, with heavy breathing during painful contractions) was also acquired. However, the quality of the images due to various interferences made extraction of useful data difficult. The background-oriented schlieren imaging recordings were processed using the DaVis 10.1 (LaVision) commercial software package. Here a multi-pass cross-correlational mapping was incorporated, where the window size, shape, percent overlap, and number of passes were stipulated, along with the type of interpolation to fill in the vector field. The displacement field could then be extracted from the calculated vector field. Each frame of the recording was subsequently filtered to reduce noise and improve contrast using MATLAB's built-in median filter and adaptive histogram equalization. Propagation of the breath in time was visually tracked in the processed images. The speed of propagation of the breath front obtained from recordings was averaged over a period of 0.35 seconds involving approximately 10 images, with every other frame used to smooth the data. This allowed us to provide an estimated speed of respiratory emissions for several different breathing conditions.

## RESULTS

All patients received regional analgesia and had full-term uncomplicated vaginal deliveries (Table 1). None of the participants had a maternal history of respiratory disease, and all patients were confirmed negative for SARS-CoV-2 infection at the time of admission and did not develop coronavirus disease 2019 (COVID-19) in the immediate postpartum period. Table 2 summarizes the speed of respiratory emissions produced from different breathing conditions during early labor and the second stage of labor. Imaging for patient 2 had the least amount of noise and optical interference due to adjacent warm surfaces, and hence, these results were used for estimation of propagation speeds for coughing and Valsalva breathing. It is noted that all three patients exhibited similar breathing characteristics for each condition. In the case of regular breathing by the patients in early labor, the breath propagates roughly at a mean speed of 1.37 meters/s (range 1.20–1.55 meters/s, Fig. 2A and Video 1). The breath front quickly leaves the field of view in the image, propagating at least 1.2 meters. For a patient who is coughing during early labor, the breath propagates faster, at a mean speed of 1.69 meters/s (range 1.22–2.27 meters/s, Fig. 2B and Video 2). The mean speeds of propagation for breathing and coughing were similar in magnitude for the early period of exhalation in others' experimental estimates and modeling efforts.[11,12] For the case of Valsalva, with the patient's forced expiration, the breath had a mean propagation speed of 1.79 meters/s (range 1.71–1.86 meters/s), even higher on average than that of typical coughing (Fig. 2C, Video 3).

## DISCUSSION

Our study indicates that a warm and vigorous cloud is produced by a patient expiring during the active and

**Table 2. Speed of Breath at Different Stages of Labor and Respiratory Action**

| Respiratory Action | Stage of Labor | Speed of Breath (meters/s) |
|---|---|---|
| Normal breathing | Early labor | 1.37 (1.20–1.55) |
| Cough | Early labor | 1.69 (1.22–2.27) |
| Valsalva | Second | 1.79 (1.71–1.86) |

Data are mean (range).

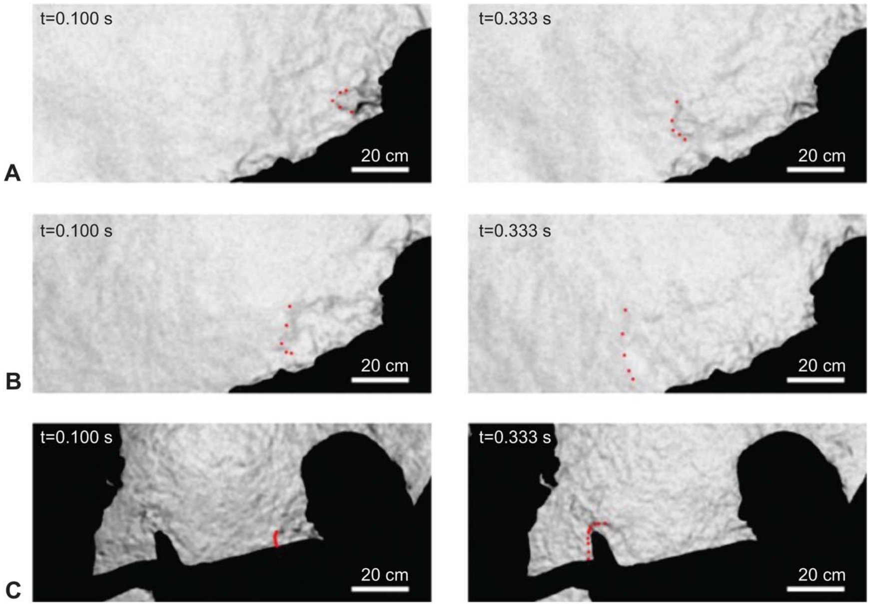
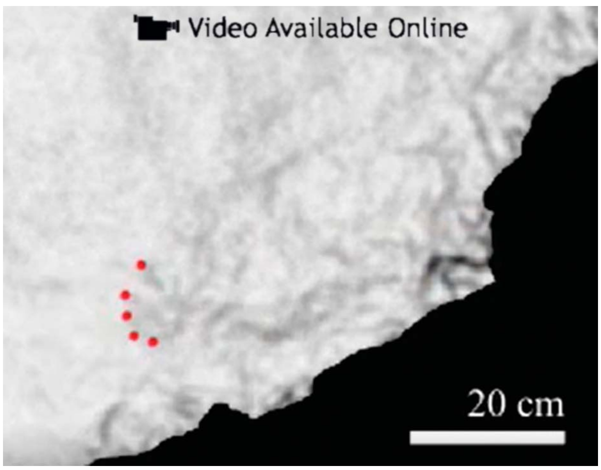



**Fig. 2.** Background-oriented schlieren imaging at different stages of labor and vaginal delivery. Patients' breath cloud produced at two time points (0.233 seconds apart) during breathing in early labor (**A**), coughing in early labor (**B**), and expulsive efforts (**C**) during second stage of labor and vaginal delivery. The *red marker* indicates propagation of the breath determined by sequential freeze-framing of the background-oriented schlieren video imaging. *Mok. Respiratory Emissions During Vaginal Delivery. Obstet Gynecol 2021.*



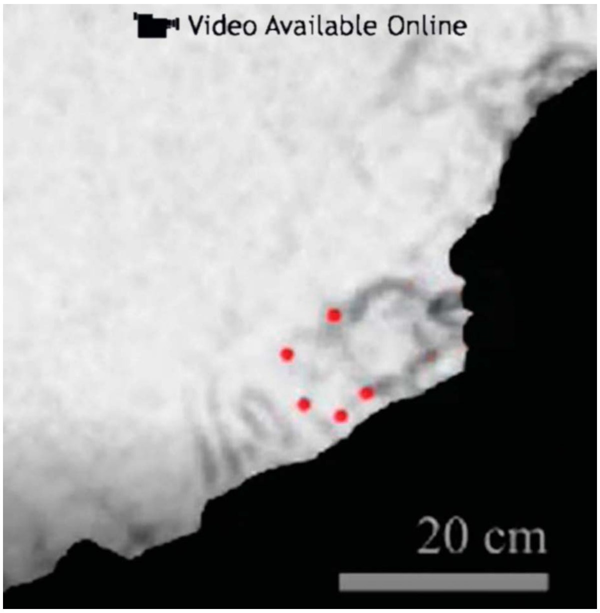

**Video 1.** Breathing in early labor. Video created by Elijah Harris and Andres Vargas. Used with permission.

second stage of labor. During active labor and with the expulsive efforts of a vaginal delivery a gas cloud can travel at a mean speed of nearly 1.8 meters/s. This is approximately 30% faster than that seen with regular voluntary breathing in early labor and at least 6% faster than expulsions produced by coughing. Given the increase in propagation speed seen with forceful expirations in active labor and during delivery, the respiratory emissions produced will travel significantly further than those produced during normal breathing.

Scan this image to view Video 1 on your smartphone.

The original ideas on respiratory infectious disease transmission are based on studies from the 1930s. Respiratory droplet emissions were described as involving either "large" or "small" droplets, otherwise known as droplets versus aerosols.[13] These findings led to the classification of airborne transmission being defined as pathogen-bearing solid residues of approximate diameter 5 micrometers or less that have the ability to stay airborne and travel further than larger droplets.[4,14] It has been suggested that this dual-size model of respiratory transmission and dichotomy of droplet and aerosol transmission is oversimplified and may be responsible for the ineffectiveness of our usual precautions in limiting the spread of SARS-CoV-2.[5,10]

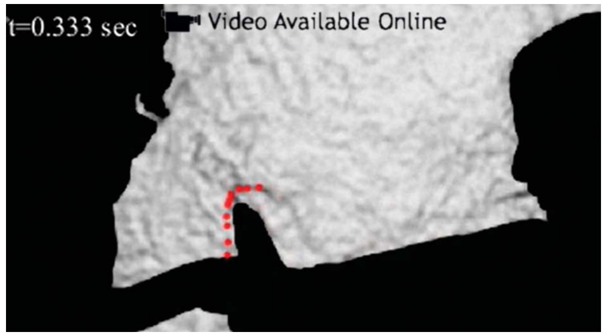
Bourouiba et al used high speed imaging to demonstrate the complexity of fluid flow after coughs and sneezes, beyond that of particle size.[10–12] Respiratory emissions are shown to be composed of a multiphase turbulent gas cloud that enters the ambient air and carries within it clusters of droplets with a range of droplet sizes that can remain suspended in the cloud for relatively long periods of time.[10,11] Multiple factors, including temperature and humidity of the air, degree of turbulence, and speed of gas cloud, alter the trajectory of the gas cloud and allow the pathogen-bearing droplets to travel significantly further and




**Video 2** Cough in early labor. Video created by Elijah Harris and Andres Vargas. Used with permission.

evaporate at an altered rate.[10] The gas cloud produced by a human cough or sneeze containing pathogen-bearing droplets have been shown to travel up to 7–8 meters with various combinations of the environmental conditions and a patient's physiology.[11,12] When comparing our study's findings to those of Bourouiba et al, the respiratory emissions of active labor are expected to produce the same or greater propagation distance than that of a cough or sneeze.

Our study demonstrates rapidly propagating respiratory emission production during active labor and pushing, and moderate-to-highly propagating emissions even before this in early labor. Although the role these warm gas clouds play in SARS-CoV-2 transmission and infection is not precisely known, these findings, in combination with health care workers' extended exposure and close proximity to patients, suggest a clear level of concern for risk of transmission of respiratory pathogens in this setting, specifically SARS-CoV-2.




**Video 3** Expulsive efforts during second stage of labor and vaginal delivery. Video created by Elijah Harris and Andres Vargas. Used with permission.

This study is preliminary and primarily descriptive in nature but performed imaging on actual patients during labor and vaginal delivery within a hospital setting, whereas prior studies that characterized respiratory emissions from speaking, coughing, or sneezing have been performed on mannequins or on individuals in a laboratory or simulation setting.[15,16] A limitation of this study is the low number of participants and good quality imaging. However, the extent of set up within the labor room and invasive video imaging required during the entire labor and delivery process to perform adequate background-oriented schlieren imaging significantly limits the feasibility of a large number of patients consenting to participation. Lastly, we recognize that this study does not address the question of particle size produced from the respiratory emissions of labor and vaginal delivery or quantify transmission risk. Alternative imaging methods such as particle shadow velocimetry could determine particle size, but such methods involve low-power pulsed LED light sources and seeded particles. This methodology would not be appropriate for use with laboring patients and can only be performed on mannequins or in a simulation lab. In addition, prior studies have clearly demonstrated that the risk of transmission of respiratory illnesses is more complex than the dichotomy of particle size and, instead, relies on multiple factors, including the complexity of the gas cloud produced, disease severity, and duration of exposure.[10–12,17] We believe this study provides the initial

Scan this image to view Video 2 on your smartphone.

Scan this image to view Video 3 on your smartphone.

description of the complex gas clouds formed during labor and vaginal delivery, a heretofore neglected focus of the risks of respiratory transmission of disease.

The second stage of labor and vaginal delivery are not currently listed as an aerosol-generating procedure by either the CDC or the World Health Organization. When obstetricians requested clarification from the CDC on the need for full personal protective equipment during the second stage of labor in March 2020, the CDC stated, "forceful exhalation during the second stage of labor would not be expected to generate aerosol to the same extent as procedures most commonly considered to be aerosol generating" and that "when respiratory supplies are restored…HCP [health care providers] should use respirators (or facemasks if a respirator is not available), eye protection, gloves, and gown during the second stage of labor."[18] As described by Morgan et al, the CDC's statement was based on limited scientific data that did not include labor and delivery units or pregnant patients and, instead, focused on the lack of equipment.[18,19] The findings from this study demonstrate that the physiologic activities necessary during the labor and delivery process produce the propagation of gas clouds with propagation speeds that may increase risk of respiratory transmission during labor and delivery.

## REFERENCES


1. Rothan HA, Byrareddy SN. The epidemiology and pathogenesis of coronavirus disease (COVID-19) outbreak. J Autoimmun 2020;109:102433. doi: 10.1016/j.jaut.2020.102433
2. Meyerowitz EA, Richterman A, Gandhi RT, Sax PE. Transmission of SARS-CoV-2: a review of viral, host, and environmental factors. Ann Intern Med 2021;174:69–79. doi: 10.736/M20-5008
3. van Doremalen N, Bushmaker T, Morris DH, Holbrook MG, Gamble A, Williamson BN, et al. Aerosol and surface stability of SARS-CoV-2 as compared with SARS-CoV-1. N Engl J Med 2020;382:1564–7. doi: 10.1056/NEJMc2004973
4. Klompas M, Baker MA, Rhee C. Airborne transmission of SARS-CoV-2: theoretical considerations and available evidence. JAMA 2020;324:441–2. doi: 10.1001/jama.2020.12458
5. Bahl P, Doolan C, de Silva C, Chughtai AA, Bourouiba L, MacIntyre CR. Airborne or droplet precautions for health workers treating COVID-19? J Infect Dis 2020:jiaa189. doi: 10.1093/infdis/jiaa189
6. Jackson T, Deibert D, Wyatt G, Durand-Moreau Q, Adisesh A, Khunti K, et al. Classification of aerosol-generating procedures: a rapid systematic review. BMJ Open Respir Res 2020;7:e000730. doi: 10.1136/bmjresp-2020-000730
7. Centers for Disease Control and Prevention. Infection control guidance for healthcare professionals about coronavirus (COVID-19). Accessed November 21, 2020. https://www.cdc.gov/coronavirus/2019-nCoV/infection-control.html
8. World Health Organization. Infection prevention and control during health care when novel coronavirus (nCoV) infection is suspected. Accessed November 21, 2020. https://www.who.int/publications/i/item/infection-prevention-and-control-during-health-care-when-novel-coronavirus-(ncov)-infection-is-suspected-20200125
9. Raffel M. Background-oriented schlieren (BOS) techniques. Exp Fluids 2015;56:60. doi: 10.1007/s00348-015-1927-5
10. Bourouiba L. Turbulent gas clouds and respiratory pathogen emissions: potential implications for reducing transmission of COVID-19. JAMA 2020;323:1837–8. doi: 10.1001/jama.2020.4756
11. Scharfman BE, Techet AH, Bush JWM, Bourouiba L. Visualization of sneeze ejecta: steps of fluid fragmentation leading to respiratory droplets. Exp Fluids 2016;57:24. doi: 10.1007/s00348-015-2078-4
12. Bourouiba L. Images in clinical medicine. A sneeze. N Engl J Med 2016;375:e15. doi: 10.1056/NEJMicm1501197
13. Wells W. On air-borne infection: study II. Droplets and droplet nuclei. Am J Epidemiol 1934;20:611–8. doi: 10.1093/oxfordjournals.aje.a118097
14. Fennelly KP. Particle sizes of infectious aerosols: implications for infection control. Lancet Respir Med 2020;8:914–24. doi: 10.1016/S2213-2600(20)30323-4
15. Canellie R, Connor CW, Gonzalez M, Ortega R. Barrier enclosure during endotracheal intubation. N Engl J Med 2020;382:1957–8. doi: 10.1056/NEJMc2007589
16. Kahler CJ, Hain R. Fundamental protective mechanisms of face masks against droplet infections. J Aerosol Sci 2020;148:105617. doi: 10/1016/j.jaerosci.2020.105617
17. Klompas M, Baker M, Rhee C. What is an aerosol-generating procedure? JAMA Surg 2021;156:113–14. doi: 10.1001/jamasurg.2020.6643
18. Morgan EA, Rodriguez D. Why "good enough" is not good enough: scientific data, not supply chain deficiencies, should be driving Centers for Disease Control and Prevention recommendations. Am J Obstet Gynecol MFM 2020;2:100165. doi: 10.1016/j.ajogmf.2020.100165
19. Tran K, Cimon K, Severn M, Pessoa-Silva CL, Conly J. Aerosol generating procedures and risk of transmission of acute respiratory infection to healthcare workers: a systematic review. PLoS One 2012;7:e35797. doi:10.1371/journal.pone.0035797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