"Cloud" Health-Care Workers

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Certain bacteria dispersed by health-care workers can cause hospital infections. Asymptomatic health-care workers colonized rectally, vaginally, or on the skin with group A streptococci have caused outbreaks of surgical site infection by airborne dispersal. Outbreaks have been associated with skin colonization or viral upper respiratory tract infection in a phenomenon of airborne dispersal of *Staphylococcus aureus* called the "cloud" phenomenon. This review summarizes the data supporting the existence of cloud health-care workers.

A variety of infectious agents can be transmitted from health-care workers to patients (1,2). Certain of these agents are transmissible through the air, which means that transmission from health-care workers can occur in spite of standard infection control measures such as handwashing. Thus, airborne transmission increases the likelihood that an outbreak can occur. While it is well known that health-care workers can transmit infections such as tuberculosis, varicella, and influenza by the airborne route, it is less well appreciated that they can also transmit certain bacterial pathogens through the air.

Bacteria transmissible through the air for which no data support transmission by health-care workers include *Clostridium diphtheriae, Haemophilus influenzae, Neisseria meningiditis, Streptococcus pneumoniae*, and *Yersinia pestis*. For all these agents except *S. pneumoniae*, the epidemiologic data supporting airborne transmission are strong enough that the Centers for Disease Control and Prevention recommends that infected patients be placed on droplet precautions (3). However, for all five agents, no episodes are well documented of health-care workers transmitting such infections to other patients by the airborne route, perhaps because workers with such infections may be too sick to work. For three other bacteria, *Bordetella pertussis, Streptococcus pyogenes*, and *Staphylococcus aureus*, strong data support airborne transmission from health-care workers to patients.

Bordetella pertussis

Although most children are vaccinated against *B. pertussis* and the vaccine is quite effective up to age 12, approximately 50% of adults are nonimmune (4). Thus, in a vaccinated population, transmission of pertussis is primarily from adults to either nonimmune children (<1 year of age) or to adults whose immunity has waned. Several well-described hospital outbreaks of pertussis have occurred in which *B. pertussis* was thought to be transmitted to or from health-care workers in a manner suggesting airborne transmission (Table 1) (5-9). Most hospital outbreaks have involved pediatric patients (5,6,8,9), but at least one outbreak has occurred in a nursing home (7). No prolonged carrier state has been identified (10,11), and transmission is most likely associated with active symptoms, particularly coughing (12). The use of air samplers and polymerase chain reaction analysis has shown that *B. pertussis* DNA can be found in the air surrounding patients with *B. pertussis* infection, providing further evidence of airborne spread (13). Terminating *B. pertussis* hospital outbreaks involves removing symptomatic health-care workers from clinical care, isolating symptomatic or exposed patients, and treating symptomatic and exposed health-care workers and patients with antibiotics.

Table 1. Hospital *Bordetella pertussis* outbreaks involving health-care workers and possible airborne transmission

Reference	Health-care workers (no.)	Other adults (no.)	Patient population	Infected patients (no.)
Kurt (5)	5	1	Pediatrics	2
	4	0	Pediatrics	0
Linneman (6)	13	0	Pediatrics	6
Addis (7)	5	0	Nursing Home	4
Christie (8)	87	0	Pediatrics	1
Nouvellon (9)	1	0	Pediatrics	1

Group A *Streptococcus pyogenes* (GAS)

Health-care worker-associated GAS outbreaks attributed to airborne spread are uncommon, associated only with asymptomatic health-care workers, and involving only surgical site infections (14-18). The health-care workers carrying GAS may be present during surgery (e.g., anesthesiologist, operating room nurse) (16,17) or not present at all (e.g., medical attendant, operating room technician) (14,15,18). In five GAS outbreaks associated with health-care workers (Table 2), volumetric or settle plate air cultures showed that the health-care workers dispersed GAS into the air. Sites of GAS colonization identified on the health-care workers include the rectum, vagina, and skin. The mechanism by which GAS becomes airborne is not entirely clear and could include increased activity (14), friction with clothing, or, in the case of an anesthesiologist who was a rectal carrier, flatulence. Such outbreaks may cause substantial illness and even death. Termination of GAS health-care worker-associated outbreaks requires eradicating the carrier state with antibiotics. In some cases eradication has been difficult because the health-care workers' family was also colonized with GAS, which may have led to initial treatment failure.

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Table 2. Hospital group A streptococcal outbreaks suggesting airborne transmission by asymptomatic health-care workers

Reference	Health-care worker	Source of GAS[a,b]	Patient population	Infected patients (no.)
McKee (14,15)	Attendant	Rectum	Gynecologic	11
Schaffner (16)	Anesthesiologist	Rectum	Surgical	20
Berkelman (17)	OR nurse	Vagina	Surgical	10
Mastro (18)	OR technician	Scalp	Surgical	20

[a]GAS air cultures were all positive
[b]GAS = Group A Streptococcus, OR = operating room

Staphyloccoccus aureus

Factors affecting the airborne dispersal of *S. aureus* have been studied more intensively than those of any other organism. In the general population, airborne dispersal of *S. aureus* is uncommon and appears to be quantitatively related to the number of *S. aureus* colonizing the anterior nares (19). Up to 10% of healthy *S. aureus* nasal carriers disperse the organism into the air (20), and females are much less likely to disperse the organism than males (21,22). Such airborne dispersers typically were surrounded by 0.01 to 0.1 CFU/m^3 of *S. aureus* and, rarely, as high as 2.6 CFU/m^3 (21,22). Hare and Thomas demonstrated that when agar plates were held directly under the noses of nasal carriers of *S. aureus*, airborne dispersal was insignificant with nasal breathing, counting, coughing 6 times, or sneezing once (23). Only with snorting did substantial dispersal occur. In contrast, when the same volunteers were moving, large numbers of *S. aureus* were dispersed into the air. This dispersal was attributed to *S. aureus* on the skin and clothing, thought to be liberated into the air by friction and movement. Coughing increases airborne dispersal of organisms other than *S. aureus*, and lack of airborne dispersal of *S. aureus* through coughing is thought to be due to its rare presence in the oropharyngeal cavity. In other studies, talking increased dispersal of organisms other than *S. aureus*, and sneezing dramatically increased the number of bacteria dispersed into the air, including *S. aureus* (24,25). Ehrenkranz demonstrated that oral tetracycline caused the number of *S. aureus* in the nose of a nasal carrier of tetracycline-resistant *S. aureus* to increase by tenfold and concommitantly increased the number of *S. aureus* dispersed into the air (26).

In detailed studies of *S. aureus* transmission in a newborn nursery setting (27,28), Rammelkamp et al. found that newborn infants exposed to nurses who handled colonized infants acquired *S. aureus* 14% of the time if good handwashing was performed and 43% of the time in the absence of good handwashing (presumed direct contact transmission). Infants acquired *S. aureus* 10% of the time when they were exposed to nurses who were not colonized with *S. aureus* and who did not handle infants colonized with *S. aureus* (presumed airborne transmission). Under these controlled circumstances, airborne transmission was about two thirds as likely as contact transmission. The infants infected by presumed airborne transmission were four times more likely to acquire the organism first in their noses than were the infants infected by direct contact (4/16 vs. 3/49; p=0.056). During a 3-year period, Nobel demonstrated that a few patients (8/3,675) were associated with airborne dispersal of *S. aureus* (29). One of eight dispersers identified was associated with an outbreak. While inactive, such patients were associated with air counts of up to 0.3 CFU/m^3 air. The highest number of *S. aureus* in the air was found in association with bedmaking of colonized patients (up to 4.9 CFU/m^3). Elevated airborne dispersal has also been associated with individual patients (30,31). Hare and Cooke found that airborne dispersal was facilitated by eczema, mycosis fungoids, or perineal carriage (31). In a few published outbreaks, health-care workers have been identified who clearly dispersed *S. aureus* into the air (32,33); in one case, dispersal was thought to be due to heavy skin colonization with *S. aureus* (15). In other outbreaks where airborne transmission has been suspected, no air cultures were performed, so the contribution of airborne transmission was not determined (34,35). Thus, although airborne dispersal from both patients and health-care workers occurs, under the circumstances previously studied, it is relatively uncommon.

However, outbreaks associated with such airborne dispersers are frequent (>10%) (29,32). Clearly, if some factor augments the ability of *S. aureus* carriers to produce airborne dispersal, the potential for *S. aureus* outbreaks to occur might be greatly increased. In 1960, the American Journal of Diseases of Children preceded an article with a brief editorial entitled "The Preposterous Cloud Baby" (36). The first sentence of the introduction stated "Once in a blue moon a journal is privileged to publish an article which introduces an important revolutionary concept." In the report that followed, Eichenwald et al. described a group of *S. aureus*-colonized, virally infected newborn infants who had the ability to disperse *S. aureus* from their noses into the air—so-called "cloud babies" (36). These researchers demonstrated by culture and epidemiologic study that a viral upper respiratory infection (e.g., with adenovirus or echo virus) was the essential "cloud factor." Up to 75% of newborn infants who carried *S. aureus* nasally became cloud babies once they acquired a viral upper respiratory infection. Most importantly, these cloud babies were also capable of causing *S. aureus* outbreaks (36). Although these infants had no greater risk for staphylococcal infection, the families of cloud babies had a fourfold higher risk for infection than the families of infants colonized with *S. aureus* that were not cloud babies. In spite of what was believed to be a revolutionary concept, no further observations about cloud babies have been published since Eichenwald's study in 1960.

In 1986 we reported that an *S. aureus* nasal carrier, a nurse, caused outbreaks in two newborn nurseries at different hospitals in association with upper respiratory infections (34). The nurse's strain of *S. aureus* and the outbreak strains were identical by phage typing. Infants' risk for acquiring staphylococcal skin disease was fivefold greater when the nurse had a upper respiratory infection. She was treated with topical bacitracin ointment and hexachlorophene baths to eradicate her *S. aureus* carrier state, and no further outbreaks of staphylococcal skin disease occurred. We postulated then that the probable source of the outbreak might be a cloud adult (4).

In 1996, an outbreak of methicillin-resistant *S. aureus* (MRSA) pneumonia occurred in an intensive care unit (33). Multivariant analysis demonstrated that the only independent risk factors for MRSA pneumonia were intubation and exposure to a single physician, who was nasally colonized with the outbreak strain of MRSA as shown by molecular typing. During the outbreak period, this physician had a

prolonged upper respiratory infection, and an experimental rhinovirus upper respiratory infection caused him to increase airborne dispersal of *S. aureus* 40-fold and become a cloud adult. The use of a mask during this experimental rhinovirus infection caused a 75% reduction in the airborne dispersal of *S. aureus*.

To a hospital epidemiologist, the identification of two cloud adults as the cause of the only two tightly clustered *S. aureus* outbreaks investigated during his career is either a striking coincidence or an indication that the frequency with which airborne transmission plays a role in *S. aureus* outbreaks has been underestimated. Many hospital outbreaks of *S. aureus* infections have been reported that were thought to be due to a single health-care worker (32-35,37-52). A few of these were probably related to heavy skin colonization (32) or sinusitis (35), but in most cases no other risk factor was apparent that could account for these persons' being capable of causing an outbreak. The role of airborne transmission was investigated in only two studies (32,33). In the group without identifiable risk factors, virtually all the health-care workers were nasally colonized with *S. aureus*. Indeed, *S. aureus* nasal colonization in health-care workers is quite common (20% to 90%) (53-56). However, if *S. aureus* nasal colonization was the only factor necessary to cause an outbreak, the high frequency of *S. aureus* nasal colonization in health-care workers should be associated with a high frequency of *S. aureus* outbreaks. Since this is not the case, some other factor(s) must modify the *S. aureus* nasal carrier state to facilitate the outbreak. One such factor is likely a viral upper respiratory infection. Since adults have an average of two viral upper respiratory infections each year (57), cloud adults may be working around patients all year.

We recently investigated the generalizability of the cloud adult phenomenon by giving six persistent nasal carriers of *S. aureus* a rhinovirus infection (58). One of the six volunteers became an unequivocal cloud adult, with a 40-fold increase in *S. aureus* airborne dispersal that could be blocked by a mask. Another volunteer had a similar increase in airborne dispersal, but it could not be prevented by a mask. The six volunteers came from a group of 18 persistent nasal carriers of *S. aureus* identified from 95 volunteers screened for *S. aureus* nasal carriage. These findings suggest that the ability to become a cloud adult could occur with a frequency of up to 6% or more in the general population.

Viral upper respiratory infections facilitate the transmission of other bacterial infections, including the following pathogens that colonize the nose: *S. pneumoniae*, *S. pyogenes*, *H. influenzae*, and *N. meningitidis* (59-62). Thus, cloud adults have the potential to play a role in the transmission of other organisms and might be involved with some of the explosive outbreaks of infection occasionally seen in day-care centers, homeless shelters, the military, and hospitals. Further work is necessary to understand the importance of cloud adults in the transmission of hospital infections.

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