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Carriage Rates of the Nosocomial Pathogen Staphylococcus aureus in Hospital Workers

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ABSTRACT

In the 1950s, *Staphylococcus aureus* caused a worldwide epidemic of hospital acquired infections (nosocomial infections). By so doing, this bacterium forced nosocomial infections to be recognized as a major problem in the health care system. In that decade, it was discovered that *Staphylococcus aureus* is vectored by nurses in three different manners, and that carriage rates increase with length of clinical exposure to sources of the bacteria in the hospital environment.

Once subdued by antibiotics, multiple drug resistant strains of *Staphylococcus aureus* are again causing major nosocomial problems. In 1989, Cookson reported that a direct relationship exists between the degree (not length) to which a health worker is exposed to a *Staphylococcus aureus* reservoir and the rate of carrier acquisition. Cookson also found that contrary to traditional thought, nurses became carriers without testing positive for hand contamination. This discovery reveals the versatility of *Staphylococcus aureus*, and it gives reason for more study dealing with the transmission of this important nosocomial pathogen.

INTRODUCTION

Before World War II and for a short period thereafter, hospital-acquired infections were recognized as an

occasional problem, but they were believed to be caused by microorganisms that originated in the extra-hospital community (Williams 1963). This community was defined as the population of non-health care workers. During the decade of the 1950s, hospitals around the world were struck by a well-known nosocomial epidemic of *Staphylococcus aureus* infections. Doctors found that no matter what was "going around" in the community *Staphylococcus aureus* infections were prevalent within the hospital. Coupled with the diversity of diseases caused by *Staphylococcus aureus*, the pandemic helped shift attention to the hospital as a special environment with its own diseases, separate from the community.

In the late 1930s sulfonamides offered the first drug treatment challenge to *Staphylococcus aureus*, but they failed because of their poor clinical performance in the presence of pus and the acquisition of resistance by the bacteria (Finland 1959). In the early 1940s the introduction of benzylpenicillin (penicillin G) temporarily solved the problem of *Staphylococcus aureus* infections, but the continued use of this agent caused the selection of resistant strains, strains which produced penicillinase (Baber 1948). By the end of the 1950s, *Staphylococcus aureus* had acquired resistance to virtually all available systemic antibiotics, including erythromycin, streptomycin, and the tetracyclines, and its virulence remained undiminished (Brumfitt 1989).

Triggered by the emergence of penicillin-resistant strains of *Staphylococcus aureus* in hospitals, many articles in the 1950s considering hospital staff (especially nurses) as vectors of transmission for this bacterium were published. Two studies in particular found that nurses are major vectors of *Staphylococcus aureus*, and that their carriage rates are directly related to the length of their clinical exposure (Rountree 1951 and Thompson 1958). Another study proposed that there are three types of nasal carriage: transient carriage (carriage for a day or less), short-term carriage (carriage for two to three days), and persistent (more than three days) carriage (Gould 1954). These classifications of *Staphylococcus aureus* carriage type are still in use today.

With the advent of semi-synthetic penicillins in the late 1950s, the *Staphylococcus aureus* problem receded. But the pathogen once again developed resistance. Methicillin-resistant *Staphylococcus aureus* was first reported in hospitals in England shortly after methicillin was introduced there in 1959 (Jevons 1961 and Shovein 1992).

In the subsequent 30 years numerous reports of infections caused by methicillin-resistant *Staphylococcus aureus* were recognized in Europe (Everett 1978), Australia (Pavillard 1982), Africa (Scragg 1978), the Middle East (Humphreys 1990), and the United States (Klimek 1976). The first outbreak of methicillin-resistant strains in the United States (Bitar 1987) in 1968 caused alarm because of

its demonstrated virulence and resistance to many antibiotics. The term "methicillin resistance" implies resistance to all penicillinase-resistant penicillins (methicillin, nafcillin, ozacillin, cloxacillin, dicloxacillin, etc.) and essentially all other beta-lactam based antibiotics (Wenzel 1991). In the late 1970s, a new strain of methicillin-resistant *Staphylococcus aureus* appeared that was also resistant to the animoglycoside antibiotics such as gentamicin, tobramycin, amikacin, and others (Brumfitt 1989). Outbreaks in the United States of various strains continued to appear throughout the 1970s and 1980s.

Today multiple antibiotic resistant strains of *Staphylococcus aureus,* the same bacterium that first brought nosocomial infections to the medical community's attention, are on the verge of becoming the first "superbugs" (a completely drug resistant bacterial pathogen) of the wonderdrug era. Some multiple antibiotic resistant strains of *Staphylococcus aureus* are only susceptible to a single drug ,vancomycin (Bacon 1987), and laboratory tests have shown that *Staphylococcus* can acquire a resistance plasmid to this drug (Schwalbe 1987). If this happens, antiinfective drugs will no longer be able to control *Staphylococcus aureus* diseases and alternative treatments will have to be found. With this stimulus, scientists are now looking for alternative methods (other than drugs) to control *Staphylococcus aureus* outbreaks.

CHARACTERISTICS OF THE PATHOGEN

Because *Staphylococcus aureus* can penetrate host tissues and evade host defenses in numerous ways, it is considered by many scientists to be the most virulent pathogen known to man (Haley 1982). But a healthy immune system can usually defend itself against many *Staphylococcus aureus* infections; thus the majority of nosocomial infections are seen in immunocompromised patients (Curry 1993). Patients with AIDS (Raviglione 1990), diabetes mellitus (Smith 1966), narcotic addictions (Tuazon 1974) or patients undergoing burn treatment (Kloos 1975), hemodialysis (Kirmani 1978), operations (Weinstein 1959), or cathaterizations (Zimmerman 1988) are at high risk of being infected by *Staphylococcus aureus*.

The pathogenic capacity of a particular stain of *Staphylococcus aureus* is due to its invasive properties which largely consist of extracellular factors and toxins it produces.

Staphylococcus aureus can penetrate its host and evade host defences with a number of factors. It can produce coagulase which clots the fibrinogen in blood plasma (the clot protects the pathogen from phagocytosis and isolates it from other host defenses). Deoxyribonuclease which lowers viscosity of exudates giving the pathogen more mobility is sometimes produced by the pathogen. It may use hemolysins which lyse erythrocytes causing anemia and weakened host defenses and make iron available for microbial growth, or

hyaluronidase which hydrolyzes hyaluronic acid (a constituent of the intercellular ground substance that cements cells together and renders the intercellular spaces amenable to passage by the pathogen). The pathogen can make leucocidins which cause degranulation of lysosomes within leucocytes (this decreases host resistance and kills leucocytes), or protein A (located in bacterial cell wall) which immunoglobulin G binds to thereby preventing complement from interacting with the bound immunoglobulin. Finally, *Staphylococcus aureus* may make streptokinase which acts as an enzyme in plasma to convert plasminogen to plasmin thus digesting fibrin clots allowing the pathogen to move from the clotted area (Prescott 1993).

Some strains of *Staphylococcus aureus* produce exotoxins (among the most lethal substances known to man) such as neurotoxins and delta cytotoxin which increase their pathogenic potential. One exotoxin, exfoliatin, causes inflammation of the epidermal layers of the skin and results in the skin peeling off (exfoliation) in a manner which resembles a reaction to being scalded (Tortora 1992).

Among the major infectious diseases caused by *Staphylococcus aureus* are: pimples, impetigo, boils, carbuncles, wound infections and abscesses, infection of lymph nodes and lymph system, septicemia, endocarditis, meningitis, enteritis, enterotoxin poisoning (food poisoning), nephritis, pharyngitis, laryngitis, bronchitis,

pneumonia, toxic shock syndrome, scalded skin syndrome, osteomyelities, and numerous others (Prescott 1993).

PROGRESS TOWARD AN ANSWER: THE COOKSON STUDY

Fairly recently, Cookson (1989) correlated nursing carriage rates with the degree of exposure to *Staphylococcus aureus* reservoirs. It was concluded that, nurses conducting intimate procedures on *Staphylococcus aureus* colonized patients are more likely to become carriers than nurses who only have casual contact. Although this may seem self evident, Cookson's article was the first to explicitly link carriage acquisition to degree of reservoir contact.

In Cookson's study, six patients, heavily colonized with *Staphylococcus aureus*, were isolated in a hospital ward without contact with the rest of the hospital. Twenty-six nurses were assigned exclusively to these patients, and were not permitted to contact other patients. During a 8 to 12-hour shift the nurses were confined to attenda single patient in the isolated ward. The infection control policy for nurses included the use of aprons and gloves for all contact procedures, but masks were not used by staff for any procedures.

The extent to which the staff dealt with the patients (and thus were exposed to *Staphylococcus aureus*) was categorized to fit a grade, and the overall grade for each

day of work was defined by the highest grade of procedure on that day.

(i) Grade 1 was superficial contact--brief exposure to a contaminated environment but no direct contact with a colonized or infected patient, e.g., delivering meals or speaking to a patient.

(ii) Grade 2 was casual contact--physical contact with patients, but no manipulation of colonized or infected sites, e.g., helping patients to wash and dress themselves.

(iii) Grade 3 was close contact--physical contact with infected or colonized sites, e.g., changing wound dressings, bathing colonized patients, or conducting urinary catheterizations.

Patients were screened for colonization by *Staphylococcus aureus* at least weekly by culturing peptone water-moistened swabs that were used to take samples from their nose, throat, perineum, catheter sites, and any abnormal skin areas or wounds. Nurses were screened for *Staphylococcus aureus* carriage by nasal swabs and finger cultures taken before and after each 8 to 10-hour duty period for the seven week duration of the study.

The environment was screened once each week before ward cleaning, which was performed twice daily. Air from each patient's room, the nurses' station, corridors, and the day room was sampled with a portable air sampler. Swabs were

used to sample floor dust, windowsills, bedsteads and points of frequent hand contact.

Plasmid and phage analysis were used in *Staphylococcus aureus* strain identification. This was done in order to determine, if possible, a correlation between patient reservoirs and nurse carriers.

The results of the study were very revealing. The environment in the experimental ward tested positive only for low levels of *Staphylococcus aureus* contamination, and the strain recorded was specific for each patient's room, i.e., the staphylococci did not appear to spread from room to room. The patients were not cross colonized with each other's *Staphylococcus aureus* strains.

The 26 nurses involved in the study were screened for *Staphylococcus aureus* a total of 870 times, and *Staphylococcus aureus* carriage was detected on 50 occasions in 13 of nurses. Three nasal carriage patterns were observed in the 13 nurses, but only on five occasions was finger carriage detected (all five on two nurses).

Of the 13 nurses, 12 were determined to be nasal carriers in the transient state (i.e. *Staphylococcus aureus* was isolated during one screening but not during the following one). Four of the 12 transient nasal carriers were also determined to be short-term nasal carriers (i.e. *Staphylococcus aureus* was isolated in only two consecutive screens). Nurse number 13 (not included with the 12 transient carriers) was determined to be a persistent nasal

carrier (i.e. *Staphylococcus aureus* was isolated during three and more screens), but it was not possible to determine when she became a carrier. She was excluded from the results.

No *Staphylococcus aureus* acquisition was detected after any of 14 grade 1 activity days and after only one of 196 grade 2 activity days. In marked contrast, grade 3 activity days were associated with all other incidents of transient or short-term *Staphylococcus aureus* carriage (n = 870). There was no significant difference in the number of grade 2 ($P = >0.2$) or 3 ($P = >0.2$) activity days for nurses one to 12, who carried the *Staphylococcus aureus*, and nurses 14 to 26, who did not. However, nurses one to 12 did perform far more wound dressings ($P<0.02$) and grade 3 activities ($P<0.001$) on grade 3 days than did nurses 14 through 26 (see Table 1).

Table 1: Percent of grade 3 procedures resulting in acquisition of *Staphylococcus aureus*.

Patient	No. of grade 3 procedures performed (% of grade 3 procedures resulting in *Staphylococcus aureus* acquisition) by nurses:	
	14 to 26	1 to 12
1	17(0)	71(6)
2	37(0)	103(13)
3	28(0)	73(7)
4	13(0)	47(11)
5	24(0)	59(10)
6	31(0)	33(0)

It has often been suggested that certain epidemic strains of *Staphylococcus aureus* have a special ability to colonize patients and staff (Shooter 1981). But until now, there been no attempts to correlate staff carriage with the duties performed. In this experiment, Cookson shows that *Staphylococcus aureus* acquisition was almost totally related to close patient contact, especially wound dressing, rather than walking into a contaminated environment or having minor contact with a patient (grade 1 and 2 activities).

Furthermore, seven of the 12 nurse carriers were infected with each epidemic strain at different times, supporting the hypothesis of continued acquisition rather than intermittent detection of *Staphylococcus aureus* carriage. This hypothesis was further supported by the large number of clear (negative) screens between each *Staphylococcus aureus* carriage episode in many of the nurses. It was also supported by the fact that the *Staphylococcus aureus* was predominantly detected after, rather than before, a duty period.

Given the above data it can be concluded that the rates at which the nurses became colonized was in direct proportion to the degree to which they came into contact with the patients. But curiously enough Cookson's results as to how the nurses became carriers contradict an earlier study done by Peacock (1980).

Peacock's study (also supported by Boyce 1981 and Thompson 1982) was roughly similar to Cookson's in that it

was conducted in an isolated burn ward. Twenty-five burn patients, five of whom were colonized with *Staphylococcus aureus*, were attended by 120 non-carrier nurses exclusively posted to them over a three week period. However, in contrast to Cookson's study, the nurses were not assigned to a single patient. The infection control policy for nurses included the use of gloves and masks for all contact procedures, but not aprons. The extent to which the staff dealt with the patients was not categorized.

Patients were screened for *Staphylococcus aureus* weekly, and nasal and finger cultures were taken from the nurses before and after each shift. The environment was also screened daily with the same method used in the Cookson study. *Staphylococcus aureus* strain identification was not attempted.

After three weeks, seven more burn patients were colonized with *Staphylococcus aureus*, and five of the original 20 uncolonized patients had been discharged. The environment tested clean in all but three of the patients' rooms.

A total of 1784 screens were performed on the 120 nurses and carriage was detected in 186 of the finger cultures. No pattern could be established in the incidence of finger carriage by nurses. Only 92 nasal cultures tested positive for *Staphylococcus aureus* carriage. Of the 92, 86 of the positive nasal carriage tests came from the same

three nurses. These nurses were assumed to have become persistent carriers.

There is still much dispute over how colonization of *Staphylococcus aureus* carriers occurs (Lidwell 1971), but people commonly blame poor nursing hand hygiene as the source of spread. This view was proposed and supported by Peacock (1980), Thompson (1982) and Boyce (1981). But in Cookson's experiment (1989), it was demonstrated that even when the nurses' hand were uncontaminated, they still acquired *Staphylococcus aureus*. Considering that the nurses in Cookson's (1989) experiments wore gloves (only five finger cultures tested positive) but not masks, it is likely, but not proven, that the *Staphylococcus aureus* was acquired from inhaled airborne particles once the grade 3 procedure was in progress. This view is further supported by the fact the nurses in Peacock's study did not wear aprons, and by touching their clothes, could have contaminated their hands after taking off their gloves. Also, because Peacock's nurses wore masks, their noses generally not transiently colonized.

Although a myriad of data was compiled during these experiments, additional factors (e.g. patient to patient contact, or nurse to nurse contact, etc.) prevented many definite conclusions. But the data strongly suggests that intimate contact with *Staphylococcus aureus* reservoirs produces higher rates of acquisition than simple contact, and that human vectors do not transmit *Staphylococcus aureus*

strictly by their hands. Depending on the situation (i.e. whether or not the nurse is wearing gloves, a mask, or an apron), *Staphylococcus aureus* can be transmitted by their hands or nose (i.e. the nurse is colonized in her nose or on her hands or both).

UNANSWERED QUESTIONS

Cookson's experiment raises some interesting questions about *Staphylococcus aureus* carriage. Are some people predisposed to becoming persistent carriers? Do persistent carriers differ from transient carriers in the rate they spread *Staphylococcus aureus* in hospitals? It is known that transient carrier rate increases when nurses begin their careers in hospitals, but does persistent carriage rate also increase? A study of this nature could be conducted on a college campus using nursing students as volunteers.

All of the above raised questions warrant further thought and study. Hopefully, some of these questions can be answered in the near future.

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