

REVIEW

The Challenge of Antibiotic-Resistant *Staphylococcus*: Lessons from Hospital Nurseries in the mid-20th Century

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In the late 1940s, epidemics of antibiotic-resistant strains of *Staphylococcus aureus* began to plague postpartum nurseries in hospitals across the United States. Exacerbated by overcrowding and nursing shortages, resistant *S. aureus* outbreaks posed a novel challenge to physicians and nurses heavily reliant on antibiotics as both prophylaxis and treatment. This paper explores the investigation of the reservoir, mode of transmission, and virulence of *S. aureus* during major hospital outbreaks and the subsequent implementation of novel infection control measures from the late 1940s through the early 1960s. The exploration of these measures reveals a shift in infection control policy as hospitals, faced with the failure of antibiotics to slow *S. aureus* outbreaks, implemented laboratory culture routines, modified nursery structure and layout, and altered nursing staff procedures to counter various forms of *S. aureus* transmission. Showcasing the need for widespread epidemiologic surveillance, ultimately manifesting itself in specialized “hospital epidemiology” training promoted in the 1970s, the challenges faced by hospital nurses in the 1950s prove highly relevant to the continued struggle with methicillin-resistant *Staphylococcus aureus* (MRSA†) and other resistant nosocomial infections.

INTRODUCTION

The 1950s was a time of transformation for postpartum nurseries in large American hospitals. With the overwhelming majority of women now giving birth in hospitals, along with the post-World War II baby boom, hospital nurseries were becoming more crowded and their staff more

taxed. At the same time, the discovery and ubiquitous use of antibiotics heralded a golden age of medicine, in which infections once deadly could now be conquered. But eventually, development of penicillin-resistant *Staphylococcus aureus* strains led to uncontrollable outbreaks in hospital nurseries across the country. The first wide-

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†Abbreviations: MRSA, methicillin-resistant *Staphylococcus aureus*

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spread occurrence of antibiotic resistance in common infections, nosocomial *S. aureus* epidemics began slowly in the late 1940s but gained severity — and attention — in the late 1950s and early 1960s.

Penicillin-resistant *S. aureus* was first noted by William M.M. Kirby at Stanford University School of Medicine in 1944. Initial analysis came from a limited number of *S. aureus* strains termed “naturally” penicillin resistant; each was isolated from a hospital patient who had not received penicillin [1]. As penicillin became widely available after World War II, incidence of penicillin-resistant *S. aureus* in hospitals rose quickly, and numerous studies found more than 10 percent of strains resistant to penicillin. By 1948, London researchers found the incidence of penicillin-resistant hospital isolates had risen to 59 percent. Penicillin-resistant strains were identified in various types of infections, ranging from septicemia to superficial skin lesions to conjunctivitis, aural, and nasopharyngeal infections. Streptomycin resistance was also observed, though exclusively in hospital isolates; community strains remained, for the time, sensitive to penicillin [2].

The antibiotic-resistance of *S. aureus* forced hospital researchers and staff to investigate non-pharmacologic infection control methods to prevent and contain outbreaks. These efforts altered nursing and staff routines, hospital equipment, and even the physical maneuvering of infants within the nursery. Hospital policies crafted throughout the 1950s and 1960s reflected continuing attempts at containing the outbreaks, inspired by contemporary laboratory research on infection transmission and control. Hospital nurseries became a platform for epidemiological researchers to effect and monitor novel strategies against transmission as administrators struggled to effectively prevent outbreaks of penicillin-resistant *S. aureus* in nurseries.

S. aureus can cause a wide variety of infections in humans, including skin infections, mastitis, pneumonia, and sepsis [3]. It is a highly prevalent nosocomial infection, infectious especially to hospital patients

with depressed immune systems. *S. aureus* may also asymptotically infect healthy adults, who then act as carriers and spread infection to those more susceptible. In a nursery setting, *S. aureus* can affect both hospitalized infants, due to their susceptible immune systems, and their mothers, due to lowered immunity and direct contact with their infants. *S. aureus* and other bacteria were treated with antibiotics for over a decade; however, the 1950s epidemic strain of *S. aureus* was resistant to common antibiotics, including penicillin and tetracyclines.

While *Staphylococcus* had long been established as a prevalent nosocomial infection, the ineffectiveness of known antibiotics to contain new resistant strains led researchers to consider non-pharmacologic avenues for infection control. Central to research on transmission of infection was the concept of a “disease reservoir,” the survival of infectious bacteria in some medium until a susceptible host can be infected [3]. When the *S. aureus* epidemic was first noticed in the mid-1940s, epidemiologists and infectious disease researchers tried to determine both the reservoir and mode of transmission for *S. aureus*. As scientific understanding of *S. aureus* developed, nurseries utilized the best available information to attempt to control and ideally prevent nursery epidemics.

Initial research focused on determining the basic elements of the epidemic: the source of infection and the chain of transmission. Investigating the source of infection, researchers surveyed the status of mothers and infants at birth, immediately post-partum, and for at least 60 days after leaving the hospital. Infants and mothers alike, healthy upon intake, showed *S. aureus* skin lesions in the days after discharge from the hospital [4]. As reports of infection at post-partum clinics grew, researchers recognized that significant and costly illnesses resulted from nosocomial infection [5]. Hospitals, now labeled as responsible for the infection, in turn prompted researchers to investigate the transmission of *S. aureus* in order to salvage the safety of obstetrics units. Researchers cast a wide net, evaluat-

ing a wide range of potential sources of infection within hospital wards, delivery rooms, and post-partum nurseries [5]. Unable to specifically cite origins of contamination or transmission, it was evident that early researchers had little idea about the actual reservoir of infection.

TRANSMISSION BY DIRECT CONTACT

Having established the hospital as the source of the infection, researchers turned first to the theory of transmission by direct contact. This mode of transmission, a basic one for infectious diseases, was a logical first choice for stumped obstetrics staff. Early results on the transmission of *S. aureus* supported their theories. As mothers suffering from mastitis reported to post-partum clinics, it quickly became evident that maternal infections were secondary, spread from a primary infection in infants by direct contact through breastfeeding [5]. Up to 93 percent of maternal infections manifested as mastitis after discharge, leading one author to state definitively that the infant was the vector of infection between the hospital nursery and the mother [6]. Other contemporary researchers supported these findings [7,8]. With overwhelming evidence for the direct transmission theory, researchers focused in on occurrences of close contact within the hospital setting.

Researchers first turned to the most apparent logical reservoir of *S. aureus*: nursery personnel that directly handle infants. Policies of weekly biological testing were enacted during epidemics, derived from the established epidemiological principle of carrier levels — that “epidemics do not occur until a sufficiently high carrier level is reached. If one can keep the carrier level below the critical point, then disastrous outbreaks will not occur” [4]. Carrier levels in nursery staff — including physicians, nurses, and support staff — reached 25 percent of all personnel, based on microbial cultures [4]. If found to have a positive culture, nurses and housekeeping staff personnel would be transferred from the ward. Carrier physicians often limited their inter-

action with infants but were allowed to remain on the obstetrics service [6]. This early discrepancy between the treatment of nurses and physicians would ultimately be reflected in infection control policies that focused nearly exclusively on nurses and support staff.

The impracticality of policies of staff removal led hospital researchers to examine hygienic measures within the nursery units. Researchers initially investigated the effects of the practices of asepsis — preventing contact with microorganisms and contaminants. The concept of asepsis evolved in the 19th century; however, practices lagged and were largely unenforced outside surgical rooms. New policies included frequent hand washing, required masks and gowns, and repeated sterilization of common instruments. When possible, common equipment was eliminated in favor of individual medical supplies and instruments [6]. Such measures might increase the cost of medical equipment within nurseries, researchers argued, but the stringent aseptic technique would prevent infection and avert the expenses of a *S. aureus* epidemic.

Doubts were raised as to the efficacy of strengthened aseptic measures as *S. aureus* infections continued to plague hospital nurseries. Donald Wysham, an epidemic intelligence service officer with the U.S. Public Health Service, in particular critiqued the narrow focus of hospital researchers while working as an acting medical epidemiologist for the Washington State Department of Health. In the first of a series of papers published in the *New England Journal of Medicine*, Wysham noted that nursery epidemics recurred despite carefully practiced aseptic technique [9]. After eliminating both mothers and obstetricians as potential carriers of infection, even the importance of nursing personnel in transmission came under fire [9]. While several nursery personnel could have introduced the *S. aureus* strain to the nursery, carriers did not have sufficient contact with infants to be considered solely responsible for maintaining the epidemic infection [9]. Wysham’s paper represented the viewpoint of many skeptical epidemiologists who cast

a long shadow of doubt on the theory of direct transmission as the definitive cause of *S. aureus* epidemics. Researchers thus began to search for a secondary mode of transmission that would more completely explain the reservoir and transmission of *S. aureus* in hospital nurseries.

TRANSMISSION BY FOMITES

Epidemiological investigation proceeded toward a secondary method of transmission: transmission by fomites. Fomites, inanimate objects that include skin cells, hair, and particles of clothing and bedding, carry infectious particles between individuals without necessitating direct contact. Researchers regarded fomite transmission as a midway step between transmission by direct contact and airborne transmission; infectious particles were not transmitted by air alone, but fomites — and their infectious companions — were considered airborne.

Investigations of fomites initially targeted hospital bedding. Bacterial cultures were taken of the fabric and dust particles immediately surrounding the bedding of both infants and mothers. *S. aureus* was not found on the bedding of mothers in delivery, once again focusing researchers on the physical surroundings of infants in the nursery [9]. The results of infant bedding cultures proved shocking: When nurses changed bedding after use by an infant with *S. aureus*, infectious particles in the air increased nearly fivefold [9]. The dust and fabric particles launched into the air during cleaning greatly facilitated the transmission of bacteria between infectious and healthy infants [4]. Nevertheless, the origin of the unique *S. aureus* — the introduction of the bacteria to the specific hospital nursery — remained unsettled.

One researcher who strove to crack the contamination case was John W. Brown, MD, of Berkeley, California. Collating research conducted on direct transmission and fomites, Brown presented an extensive list of environmental contaminants and hygienic policy recommendations for preventing *S. aureus* outbreaks at the 1958 AMA Confer-

ence on *Staphylococcal* Infections. His report, which encompasses nosocomial infections of the entire hospital, labeled the newborn nursery as the “most important reservoir of the epidemic type of staphylococci in a hospital;” thus, Brown focuses his policies on the nursery environment [10]. Brown discussed nearly 30 recommendations ranging from basic hand washing and gown technique to the handling of food and linens to the lighting and ventilation in hospital wings. He gave an inventory of potential fomites, including common combs, nail files, thermometers, linens, linen carts, and even the ink pad by which babies are foot-printed; each of these, his policies declared, needed to be discarded and replaced by individual, sterile, and disposable equipment in order to prevent fomite transmission [10]. Together, his recommendations comprised a complete overhaul of nursery supplies and housekeeping regimens.

While Brown’s report suggests that a complete overhaul of hospital nurseries is necessary to prevent infection, some of his recommendations were hardly novel. In a 1945 article, “Three Procedures That Help Curb Airborne Infection,” hospital administrators are urged to reduce cross-infection by treating bedclothes and floors with oil to hold dust, lint, and other fomites [11]. Hospital housekeepers are recommended to practice “sanitary ventilation” by employing UV light and a system of moving air, aiming to cleanse both hospital air and equipment of infectious particles [10]. These practices, informed by a general understanding of germ theory, nevertheless resurface in Brown’s recommendations as targeted strategies of preventing cross-infection.

Not all of Brown’s recommendations for countering fomite transmission targeted nursery equipment and layout. Recognizing the antibiotic-resistance prevalent in epidemic *S. aureus*, Brown endorsed the use of hexachlorophene, an antibacterial detergent [12]. Later studies show that hand washing with hexachlorophene became mandatory practice in nursery wards [12]. Hexachlorophene powder was also developed for use in an infant skin treatment. During a

high-density outbreak, its use resulted in a significantly diminished incidence of staphylococcal infections, with a far more appreciable effect than changes in nursing and housekeeping routine [9]. Given the dependence on antibiotics by physicians of the period, an analog antimicrobial powder that affected *S. aureus* tempted researchers as a possible medical innovation for controlling epidemics.

AIRBORNE TRANSMISSION

Despite these policies targeting direct and fomite transmission, epidemics of *S. aureus* continued throughout the late 1950s and early 1960s. Outbreaks continued to be reported throughout the United States, with infection affecting nearly 50 percent of newborn infants [6], suggesting the existence of the third transmission pathway. Given the longevity of the epidemics — now occurring for nearly a decade throughout the United States — researchers turned to a final epidemiologic investigation: airborne transmission, with the infected infants themselves as the reservoir of the *S. aureus* bacteria.

Wysham, who initially questioned the validity of transmission by direct contact, similarly debated Brown's contention of the vital role of airborne transmission. Previous evidence had shown that *S. aureus* colonized the respiratory tracts of infants as a primary infection, suggesting air as an agent in cross-infection. However, without conclusive evidence that the *S. aureus* present in the air was the same strain that colonized in infants' throats and noses, the theory of airborne transmission was not yet scientifically validated.

In order to investigate airborne transmission, Wysham took cultures from the nose, throat, and skin of all infants as well as air samples in various places on the nursery floor during a major outbreak affecting nearly all city hospitals in Seattle, Washington, from early 1955 through 1956. Utilizing phage typing and antibiotic-sensitivity testing, Wysham "fingerprinted" the *S. aureus* present in each culture. By matching the fingerprints of different samples,

Wysham traced the path of the bacteria within the nursery and confirmed the existence of a third, airborne pathway for *S. aureus* infection.

THE ROLE OF THE LABORATORY

The confirmation of airborne transmission underscores the importance of laboratory techniques to epidemiological research. Typing and resistance testing provided a "fingerprint" of the *S. aureus* strain, which was utilized to match strains of *S. aureus* across hospitals and cities. As a result, an "epidemic strain" of *S. aureus* was identified in 65 percent of reported hospitals worldwide. This strain, typed as 80/81, was resistant to penicillin in more than 90 percent of cases — deeply troubling to physicians who relied heavily on antibiotics for both treatment and prophylaxis [8].

With the increasing dependence on lab techniques, discrepancies among hospitals reporting *S. aureus* came under new scrutiny. Previously, some hospitals had claimed to be completely free from type 80/81 or *S. aureus* infections altogether; those hospitals rarely had the laboratory resources to "fingerprint" infectious strains. It is not coincidental, wrote one researcher, that "staphylococcal disease is a major problem in the better hospitals — the ones which have pathologists and good laboratories and a hospital infection record keeping system" [4]. Health department labs became overloaded from processing cultures; underfunded, rural, or older hospitals without such equipment lagged behind in reporting, research, and treatment of *S. aureus*.

In most hospitals, the need for regular cultures of air, bedding, and infants, followed by a systematic review and revision of nursery procedures and infant care, could not continue to be handled by already overworked nursing staff [8]. A novel and valued position arose within the hospital to meet this need: the hospital epidemiologist [4]. This position required training in laboratory science, public health, and hospital policy, resulting in a uniquely dynamic position within the hierarchical hospital system. The

hospital epidemiologist organized efforts in reporting and surveillance, tracked hospital discharges and outbreaks, and conducted follow-ups with a community-wide perspective. These practices were highly effective in recognizing and reporting outbreaks but did not lessen or prevent *S. aureus* epidemics.

RESTRUCTURING THE NURSERY

The resulting shift in hospital policy was once again non-pharmacologic, instead acting upon the physical structure of the nursery space. Having determined that infants themselves acted as a reservoir, hospitals made arrangements to separate infants from each other. Hospital administrators first decreased the number of infants held in each room by putting up temporary walls to create sections within nurseries [9]. Nursery designs were altered to include “cohort nurseries;” each room housed a few infants of the same age, preventing exposure of newborn infants to older infants. Nurses limited their work to a particular cohort to further decrease the risk of cross-infection. However, high birth rates coupled with a nursing shortage ultimately led to nursery overcrowding and limited the feasibility of the cohort design.

Overcrowding in nurseries was not a novel problem. During WWII, when nurseries were particularly overcrowded, “sporadic outbreaks” of *S. aureus* were encountered, perhaps a precursor to the epidemic strain [4]. In response to overcrowding, obstetricians altered discharge policies, thereby limiting the infant reservoir for *S. aureus* bacteria. Researchers cited a “direct relation in infants between the proportion of positive nose and throat cultures and the length of nursery stay” [8]. By shortening hospital stays, the infant reservoir for *S. aureus* would be limited, and infant exposure to the hospital environment would decrease. One study in particular suggested that infants were most likely to be infected after the third day of hospital life [6]. So, hospitals countrywide began to regularly discharge mothers and infants by the third day after delivery, except in case of complications.

Retrospective studies supported this effort to decrease overcrowding; in one major Seattle hospital, the *S. aureus* epidemic temporarily disappeared at the lowest point of the nursery census, and the epidemic fully terminated when no infants were born during a 3-day period [9].

The hospital effort to decrease the nursery census coincided with a cultural obstetrics movement: rooming-in. Rooming-in, the practice of keeping a newborn infant in the mother’s hospital room rather than in a shared nursery, was developed to create a relaxed environment during a mother’s delivery and immediate post-partum period [13]. Preserving the integrity of the mother-infant relationship, rooming-in shifted the birthing process back under the power of the mother and family, rather than the obstetrician [14]. Regardless of its psychological roots, the practice of rooming-in included the nearly complete separation of infants from each other — countering airborne transmission — and a minimization of infant exposure to the hospital environment — countering direct and fomite transmission. Hospitals turned to rooming-in not as a psychological reform of delivery practices, but as a method of infection control. In studies comparing rooming-in units and communal nurseries at the same hospital, rooming-in was shown to drastically limit cross infection. In one hospital, infection rates fell from 37.1 percent to 6.8 percent [6]; in another, the carrier rate fell from 80 percent to 8 percent during a week-long hospital stay [8]. Rooming-in was initially used as a secondary method of infection control, when aseptic and surveillance practices failed to terminate an epidemic. The most effective termination measure, researchers found, was compulsory rooming-in of the infant with the mother. As hospital designs focused on smaller rooms within nurseries to limit cross-infection between infants, epidemiologists recognized its promise as an infection control technique and ultimately acted as advocates for the rooming-in movement.

Nurses often performed compulsory rooming-in of infants with mothers during an infectious outbreak [6]. Non-epidemic

rooming-in policies called for complete isolation of mother and infant, limited interaction with nurses, restriction of the movement of the mother within the hospital, and a prohibition on contact between the infant and any adult visitors. These strict measures, especially the compulsory mandate, sparked controversy among rooming-in advocates. As documented by Dr. Edith Jackson, director of the Yale Rooming-In Project from 1946 to 1954, “[Rooming-in as infection control], while it was constructive for the hospital emergency situation, tended to confuse the thinking about rooming-in, since the basic ideas of initial rooming-in plans were that rooming-in should be elective [sic], and that there should be *constant availability of a nurse to meet the mothers’ immediate needs and questions* [sic]” [14]. Rooming-in as enacted by epidemiologists appeared antithetical to the intended philosophy of rooming-in, a relaxed post-partum atmosphere centered on the mother’s psychological and physical needs.

This criticism was met largely with skepticism by obstetricians. Many physicians disregarded Jackson’s ideal rooming-in conditions outright, instead faulting mothers for laziness. Others accused mothers of envisioning hospital stays as vacations, free of child care concerns and maternal responsibility [7]. This attitude was shared in other written reports, which characterized mothers as purposefully undermining the rooming-in system by requesting “unnecessary” nursing assistance to avoid caring for their own newborns. Researchers’ concerns were for the lowering of epidemic disease rates, not the birthing experience of individual patients.

COMPREHENSIVE HOSPITAL POLICY?

By the late 1950s, policies of asepsis, hygiene, nursery design, surveillance, and reporting practices had all been inspired by scientific evidence and research. However, rather than smoothly shifting between policies, the reality within hospital walls was much more disordered. Hospitals often enacted different parts of multiple researcher recommendations, limited in their efforts by

funding, staff shortages, or basic hospital layout and design. And while researchers continued to publish findings, the scientific consensus was less striking than the results published in individual papers. The surveillance and control of outbreaks were “a new concept in preventive medicine,” and academic understanding was far from complete. Nearly all aspects of *Streptococcus* epidemics — epidemiological characterization, virulence, and manner of transmission in particular — had yet to be fully appreciated [8]. Every hospital policy had been inspired by a specific epidemiological conclusion, yet the strength of those conclusions as individual, all-encompassing truths was called into question. Hospitals, desperate to not only terminate existing epidemics but also prevent future epidemics, adopted a mix of policies as a result.

In a review of these research reports, a few basic elements emerged as common to all hospital policies. The most striking of these shared policies was an emergency response plan: a set of rules and procedures that went into effect at the highest points of a *S. aureus* outbreak. Emergency control measures included mandatory early discharge, hyper-vigilant asepsis techniques, isolation of infected carriers, and the consecutive closing, washing, and re-opening of individual nursery rooms [4]. These practices were characterized by a narrow focus on hospital policy, without explicit regard to patient experience. Such emergency measures served as a last resort for desperate hospital epidemiologists, who combated such outbreaks with broad measures inspired by all scientifically validated modes of transmission.

Visibly absent from hospitals’ emergency response plans was the consideration of antibiotics. The 80/81 strain of *S. aureus* had been identified as resistant to penicillin, tetracyclines, and streptomycin, although researchers acknowledged that antibiotic sensitivity was constantly changing. Further research demonstrated the extent of the spread of resistance. By 1959, 92 percent of common *S. aureus* strains showed resistance to penicillin [8]. These results sparked controversy in the medical community over the

continued and proper use of antibiotics to prevent infection.

Health care providers who had come to rely on the widespread use of antibiotics were now faced with the challenge of the drugs' ineffectiveness, possibly caused by their own liberal prescribing practices. The debate in hospitals and medical literature over antibiotic resistance was neatly summarized by a community hospital physician: "Certain groups believe that an antibiotic to which the particular strain is sensitive should be administered prophylactically ... other groups believe that antibiotic prophylaxis not only is unnecessary but may prove harmful, as *S. aureus* is an organism which rapidly develops antibiotic resistance" [8]. In some hospitals, infants received daily doses of alternative antibiotics such as aureomycin or acquacillin in the hopes of preventing *S. aureus* outright [4]. In these cases, nursery personnel defended their continued policies of antibiotic prophylaxis, determining the minimal blood level of antibiotic required to protect an infant and claiming a low chance of developing resistance. Yet the ease that *S. aureus* acquired resistance gave further weight to the necessity of non-pharmacologic policies, including asepsis, isolation, early hospital discharge, and all those discussed above, as a primary method for combating infectious disease.

CONCLUSION AND OUTLOOK

As understanding of the transmission of *S. aureus* developed, so did hospital policies design to block its spread. Throughout the mid-century, researchers proposed methods to control infection by direct contact, fomites, and airborne particles, with limited effectiveness. No single policy proved effective enough to prevent outbreaks; rather, a combination of policies served to contain epidemics and identify endemic strains. Modified nursery layout, coinciding with the rooming-in movement, significantly altered patient experiences in the hope of preventing severe illness. Ultimately, the challenges of penicillin-resistant *S. aureus* demonstrated the need for widespread epidemiologic sur-

veillance of laboratory cultures of community and hospital strains, a system still utilized today.

The concerns of the 1950s and 1960s still weigh heavily in modern hospitals. methicillin-resistant *Staphylococcus aureus* (MRSA), which emerged in the 1990s, now accounts for an estimated 18,650 deaths each year, surpassing the mortality of AIDS infections in the United States [15]. MRSA has become endemic not only in large teaching hospitals but smaller community hospitals. Susceptibility is limited to vancomycin, and the development of novel antibiotics has not kept pace with rapid evolution of antibiotic resistance [16]. Since 2005, community-associated MRSA strains have been documented to spread between healthy newborns on labor and maternity units within a single hospital, causing significant and severe illness. While this transmission closely resembles that of penicillin-resistant *S. aureus* of the mid-century, community-associated MRSA infections remain less frequent in health care settings [17]. Currently, health care-associated MRSA consists of 85 percent of all MRSA infections and is most commonly associated with invasive procedures, nursing homes, and long-term care facilities [18].

Still facing the limitations of antimicrobial agents, nursing and medical personnel continue to rely on surveillance, sanitation, and physical infection control measures to contain *S. aureus* outbreaks in hospitals and community care centers. During a MRSA USA300 outbreak at a Texas tertiary care center NICU from 2004 to 2005, infection control measures included hygienic practices of hand washing, gowns and gloves, implementation of cohort nursery design and isolation of suspect carriers, disinfection of NICU equipment, and routine, repeated bacterial cultures of nursing and medical personnel [19]. While these measures used modern-era germicidal wipes, decontamination baths, and susceptibility testing of *S. aureus* isolates, the underlying policies of non-pharmacologic infection control remain unchanged from the initial emergence of penicillin-resistant bacteria.

Modern infection control measures have not yet answered the challenges first presented in the 1950s and 1960s. A study of mandatory active MRSA screening in an urban Midwestern hospital in 2008 showed increased average laboratory costs, increased nursing resource use, and unacceptably high false-positive rates leading to negative psychological effects on infants' parents [20]. The same study highlighted the role of nurses as front-line care providers with relevant insight into health care policy. The need for a MRSA screening test with high predictive value, low cost, and quick turnaround to provide clinically relevant diagnosis cannot be overestimated. Yet significant progress has been made in sequence typing, used to identify and track MRSA strains globally. A recent *New England Journal of Medicine* article identified whole-genome sequencing with a rapid-sequencing platform as a timely, meaningful method of both diagnosis and retrospective tracking of transmission in hospital nurseries [21]. Rapid sequencing avoids disruptive ward closures and aids the tracing of microevolution of MRSA to guard against increased resistance and delays due to lack of training and overloaded lab personnel. However, such methods are still based in epidemic control and surveillance, with prevention of outbreaks still out of reach.

The historical experience of researchers and health care providers highlights the difficulty of dealing with antibiotic-resistant *S. aureus* in an age of widespread antibiotic use. This circumstance is mirrored in today's medical community, as MRSA plagues both major urban hospitals and community health centers. Sharing many features with mid-century *S. aureus* epidemics — multiple pathways of transmission, specific highly virulent strains, and antibiotic resistance — the MRSA epidemic is challenging hospitals, physicians, and nurses to use biochemical methods of identification alongside non-pharmacologic methods of infection control. Nursing personnel, who have assumed the daily responsibilities of infection control both historically and presently, may emerge as active participants in the imple-

mentation and evaluation of infection control policies [20]. As continued antibiotic use spurs increasing resistance in common bacteria, non-pharmacologic methods of infection prevention and control, including those inaugurated in the 1950s and 1960s, will remain vital practices for hospitals and physicians worldwide.

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