

## Multidrug-Resistant Staphylococci in the Environment

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**Abstract.** Staphylococci are still one of the leading causes of nosocomial and community-acquired infections. Recently large numbers of multidrug-resistant staphylococci have been recovered from diverse environmental sources, such as drinking water supplies, foodstuffs, the mucosa of humans and farm animals and hospital environments. This increasing incidence of  $\beta$ -lactams and glycopeptides-resistant staphylococci in the environment is of public health concern. This paper aims to review the prevalence and the possible potential health risks associated with the spread of multidrug-resistant coagulase-positive and coagulase-negative staphylococci in the environment.

**Keywords:** Antibiotic resistance, Biofilm, Environment, Staphylococcus, Public health, Water

### 1. Introduction

The staphylococci are Gram-positive spherical cells, usually arranged in grapelike irregular clusters. The genus *Staphylococcus* has at least 40 species, which are separated in to two major groups on the basis of their ability to clot (coagulate) blood plasma by the action of staphylocoagulas [1]. The coagulase-positive staphylococci (CoPS) include pathogenic species such as *Staphylococcus aureus*, while the coagulase-negative staphylococci (CoNS) include species that are part of the normal flora of the skin in humans such as *Staphylococcus epidermidis* [2]. Staphylococci are ubiquitous in the environment, and found as part of the normal flora in soil, water, skin and mucous membranes of humans and warm-blooded animals, and have been frequently isolated from a wide range of foodstuffs such as dairy products and meat [3].

The coagulase-positive *Staphylococcus aureus* is a major cause of various community and hospital acquired infections. It causes skin and soft tissues infections, surgical site infections, and bone and joint infections. *Staphylococcus aureus* is a common cause of hospital-acquired bacteraemia and it is associated with hospital-acquired respiratory tract infections [2, 4, 5]. It is an important food-borne pathogen that usually associated with raw unpasteurized milk of dairy cattle suffering staphylococcal-associated mastitis [3, 6]. The nasal carriage of *Staph. aureus* in healthy adults was reported to be around 30 % in the population [5]. The coagulase-negative staphylococci, are common components of the human skin microflora, and play an important role in flavor and aroma formation through the production of fermented foods, such as cheese and sausage. In recent years, there has been an increase in cases of nosocomial infections in which coagulase-negative staphylococci are implicated [2, 3, 7].

Antibiotic resistant staphylococci are major public health concern since the bacteria can be easily circulated in the environment. Infections due to methicillin-resistant *Staphylococcus aureus* (MRSA) have increased world-wide during the past twenty years [4, 8]. Multiple drug-resistant *Staph. aureus* have been frequently recovered from foodstuffs [9, 10], water and biofilm formation [9, 11], nasal mucosa of humans [9, 12], clinical cases [13] and livestock [14]. Similarly, methicillin-resistant *Staph. epidermidis* (MRSE) have been increasingly found to be associated with nosocomial infections [2]. Multiple antibiotic-resistant CoNS were also recovered from food, potable water and wastewater water [9, 15, 16]. This paper aims to

review the prevalence and significance of multidrug-resistant coagulase-positive and coagulase-negative staphylococci in the environment from a public health standpoint

## **2. Incidence and public health significance of multidrug-resistance staphylococci in the environment**

### **2.1. Aquatic environments**

The presence of staphylococci in different types of water, particularly those designated for human consumption and/or recreation has been documented [9, 15, 17]. In drinking water, staphylococci, may be regarded as one of the genera that are commonly found in water supplies as Heterotrophic Plate Count (HPC) bacteria [15, 18]. Although it was suggested that it is not possible to establish health-based standards for the presence of HPC bacteria in drinking water, the presence of large abundance of *Staphylococcus aureus* in water intended for human consumption, may represent potential health hazards, especially if these strains possess determinants of antibiotic resistance and enterotoxin production [9, 19]. Pavlov et al. [20] found that *Staph. aureus* isolated from drinking water were the most virulent and resistant to multi-antibiotics among all of the HPC bacteria recovered from water supplies in South Africa. Furthermore, water contaminated with *Staph. aureus* was reported to cause food poisoning when used to cool boiled eggs [21]. As regard CoNS, concerns over their presence in drinking water supplies have been recently addressed, and it was suggested that multidrug-resistant CoNS that are colonizing distribution network, may pose health threats considering their ability to form biofilm formation, that may harbour potential waterborne pathogens, as well as their role as a reservoir for transferable resistance genes to other potential bacterial species [9, 15].

The source of *Staphylococcus aureus* in bathing water was found to be bathers themselves [19, 22]. The presence of the organism in high concentrations in recreational fresh water (swimming pools) [22] and marine water (bathing beaches) [23] has been associated with skin and eye infections in bathers [24, 25]. Moreover, *Staphylococcus aureus* isolated from marine bathing water were found to be resistant to multiple antibiotics including methicillin, vancomycin, erythromycin and more [22]. Given their ability to resist chlorine, being halophilic and being able to adapt to diverse environments, it was suggested that staphylococci should be considered as an effective indicator for predicting the sanitary qualities of fresh and marine bathing waters [26, 27, 28].

### **2.2. Food-manufacturing environments**

The contamination of foodstuffs by *Staphylococcus aureus* is an important cause of food poisoning. Humans are the main and the most frequently source of food contamination, particularly the species colonizing the skin and the interior nares of individuals and food handlers. Livestock infected with staphylococcal-associated mastitis is also a common source of the organism in foodstuffs [5, 6, 9, 10, 16, 29, 30]. Cross contamination of foodstuffs by staphylococci during various steps of food processing and manufacturing is very likely to occur, as a result of either using heavily contaminated materials (e.g. unpasteurized milk), or poor hygiene practice throughout the production process [9, 10, 29]. For instance, the contamination of poultry carcasses by *Staphylococcus aureus*, was attributed to the colonization and persistence of the bacteria on de-feathering machines [31]. Similarly, colonization of staphylococci on stainless steel pipes in milk processing plants was found to be the source of the organism in dairy products [32]. The colonization of staphylococci on food processing machines was, in part, related to their ability to produce mucoid growth, that aids attachments of the cells to surfaces (i.e. the formation of biofilm), with its effect on key characteristics such as resistance to disinfectants [31, 32, 33]. In addition to their ability to cause food poisoning, the presence of antibiotic-resistance determinants in *Staphylococcus aureus* strains in foodstuffs and/or food-manufacturing environments could worsen the situation, as infections due to these strains could be difficult to be treated, and once they are colonize food-production environment, it is unlikely to be eradicated [5, 6]. In other sittings, i.e. slaughterhouses, abundant methicillin-resistant *Staphylococcus aureus* (MRSA) that are naturally-carried by livestock, were found to contaminate different areas and compartments of slaughterhouses, and create a risk factor for personnel working in these sittings, particularly those who come in close contact with live animals [6, 34, 35].

The coagulase-negative staphylococci (CoNS) are ubiquitous bacteria that are encountered in various habitats, including food-production environments. They can be naturally found on the skin and the nasal mucosa of livestock, food-manufacturing workers; food-processing equipments and even involved in the production of fermented foods, such as ripened cheese and fermented sausages [2, 3, 9, 16, 32, 33, 36,]. The consumption of food containing CoNS is considered to be safe, since to-date, no available reports of CoNS-associated health risks following the ingestion of such foodstuffs [3, 9, 37], nevertheless, the occurrence of multidrug-resistance CoNS in foodstuffs, or food-production environments, together with their ability to serve as a reservoir for the dissemination of resistance genes to other pathogenic species, such as *Staph. aureus* in food matrices and/or production environments, suggests that only specifically selected, antibiotic susceptible strains of CoNS should be used in starter cultures [3, 9, 38].

### **2.3. Home environment**

High levels of *Staphylococcus aureus* and MRSA were detected from residential indoor bioaerosols. The levels of multidrug-resistant staphylococci were found to be higher indoors comparing to the bioaerosols outdoors [39]. The incidence of staphylococci, particularly multidrug-resistant strains in home environment can originate from residents themselves as the organism can easily be shed from narse, ulcers and eczematous skins during daily home activities [6]. Another potential source of the organism in home environment is the companion animals [6, 40]. Transmission of the organism between pets and their owners may occur in house environment, thus, with lack of good hygiene practice and cleaning, the spread of the bacteria, particularly antibiotic-resistant strains, to household contacts is inevitable and probably cause potential health risks [6, 39, 40, 41].

### **2.4. Hospital environments**

*Staphylococcus aureus*, particularly antibiotic-resistant strains continues to be a major cause of hospital-acquired infections [2, 4]. In recent years, the frequency with which coagulase-negative staphylococci are implicated in nosocomial infection is increasing, particularly catheter-related bacteraemia and post-operative endophthalmitis [2, 7]. The bacteria are shed by patients and healthcare personnel on surfaces. Dust, dirt and bioaerosols are also potential sources of the organisms in hospital environment which may become extensively contaminated and colonized by the bacteria, especially MRSA [42, 43, 44]. It was found that the removal of dirt in hospital environment may have an impact on the control of staphylococci, particularly MRSA [42]. Moreover, hydrogen peroxide vapour was found to be very effective in eradicating MRSA that are not eliminated by conventional cleaning methods in healthcare environments [43].

## **3. Survival of staphylococci in nature**

The ability of staphylococci, particularly antibiotic-resistant strains, to survive for long periods in diverse environments has received considerable attention by public health authorities. Staphylococci have remarkable ability to adapt to diverse environmental conditions, therefore research studies have revealed that they are capable of surviving for weeks in recreational fresh and marine waters [27, 28, 45], melamine countertops, vinyl floor tiles and glass (i.e. fomites) [46], foodstuffs [47, 48] and on coins [49]. In aquatic environments, staphylococci may be able to persist for several days under dark conditions, however, solar radiation and temperature were found to be the most influential factors affecting their survival in aquatic environments [27, 28]. On fomites, MRSA was shown to survive for up to 60 days; this indicates that good code of hygiene practice is vital for the control of hospital and community-acquired staphylococcal infections [46]. Recently, Szczawiński et al. [50] found that the use of ceramic tiles coated with TiO<sub>2</sub> films in hospitals, food processing plants and other places, where UV radiation is applied for disinfection should improve the efficacy of staphylococci eradication. Artificially inoculated staphylococci in processed cheese were found to survive for up to 270 days at 22 °C, and about 100 days less survival at 4 °C [47]. Conversely, in very low pH foodstuffs (e.g. salsa), survival of staphylococci was longer at 4 °C, since acidic conditions hindered the organism to persist for longer periods at ambient temperatures, as well as inhibited the production of enterotoxin [48].

## 4. Concluding remarks

Staphylococci, particularly antibiotic-resistant strains are a major cause of hospital and community-acquired infections. These bacteria are ubiquitous and wide spread in the environment; they have remarkable ability to survive well under diverse environmental conditions. They are able to persist for long periods in various habitats; in addition they may act as reservoir for the dissemination of resistance genes to other species, including potential pathogens. Their ability to survive and acquire resistance genes in the environment may, in part, explain why they are still continue to be a major potential pathogen to humans and animals.

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