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Carriage of *Staphylococcus aureus* among food handlers: An ongoing challenge in public health

Daniela Bencardino [*], Giulia Amagliani, Giorgio Brandi

Department of Biomolecular Sciences, University of Urbino "Carlo Bo", PU, Italy

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ABSTRACT

Staphylococcus aureus is a commensal bacterium known to colonize the skin, nares, and gastrointestinal tract of humans. Asymptomatic workers can contaminate food via manual contact or through respiratory secretions thus becoming the source of staphylococcal food poisoning. This gastrointestinal intoxication occurs after the ingestion of food contaminated by enterotoxin-producing *Staphylococcus aureus*. Although most individuals overcome the infection without medical assistance and make a full recovery, in rare cases the infection can be life-threatening. Hence, *Staphylococcus aureus* food contamination represents a serious problem for both the food industry and healthcare systems. In the last few decades, many studies have investigated the prevalence of carriers among food handlers. We present an overview of all investigations carried out on nasal carriers working in different food industry settings highlighting the risk associated with cross-contamination.

1. Introduction

1.1. Pathogen and infections

Staphylococcus aureus (*S. aureus*), a spherical Gram-positive bacterium, is a versatile human pathogen able to colonize a wide set of host niches (Balasubramanian et al., 2017; Lakhundi & Zhang, 2018). It is a skin and mucosae commensal bacterium that is responsible for a plethora of opportunistic infections ranging from mild to life-threatening illnesses (Oliveira et al., 2018; Sakr et al., 2018).

Bacteremia, infective endocarditis, osteoarticular, skin and soft tissue infections, and device-related infections are the major diseases caused by *S. aureus*. Among them, bacteremia is the best known clinical manifestation and hemodialysis patients are at increased risk due to the frequent use of intravascular devices through which the pathogen can gain access (Tong et al., 2015). A complication of bacteremia is infective endocarditis that occurs when damaged cardiac endothelium becomes colonized by *S. aureus*. Many host-related risk factors have been identified including drug use, congenital heart disease and the insertion of cardiac prosthetic material (Bouchiat et al., 2015). Noteworthy, *S. aureus* is the leading cause of the three major types of osteoarticular infections (osteomyelitis, native joint septic arthritis, prosthetic joint infection). The reason lies on cell-surface proteins that mediate the adherence of pathogen to components of bone matrix and collagen (Tong et al., 2015).

Furthermore, *S. aureus* causes many skin and soft tissue infections ranging from mild cases of impetigo and cellulitis to severe illnesses such as surgical site infections, cutaneous abscesses, purulent cellulitis, and necrotizing fasciitis (Tong et al., 2015). Finally, *S. aureus* is able to colonize prosthetic cardiac valves, prosthetic joints, breast implants, and other types of devices. For these reasons, improved management of surgical approaches through the implementation of stringent hygiene measures are strongly recommended to reduce the associated risk (Eid et al., 2012; Tong et al., 2015).

Given the severity of these infections, we believe that a stringent screening of healthy individuals should be strongly considered in all settings characterized by close contacts.

1.2. *S. aureus* colonization

Multiple body sites (the skin, rectum, inguinal area, gastrointestinal tract and axilla) can be colonized by this pathogen, but the anterior nares represent the main reservoir. Healthy individuals can be asymptomatically colonized by *S. aureus* and classified in the following categories: persistent (10–20%), intermittent (30–50%) or non-carriers (Ryu et al., 2014; Sakr et al., 2018). Notably, colonization represents an important risk factor for infection (Ryu et al., 2014).

In 1931, Danbolt provided the first evidence of the relationship

* Corresponding author. Department of Biomolecular Sciences University of Urbino via Arco d'Augusto 2, 61032, Fano, (PU), Italy.
E-mail addresses: daniela.bencardino@uniurb.it (D. Bencardino), giulia.amagliani@uniurb.it (G. Amagliani), giorgio.brandi@uniurb.it (G. Brandi).

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between nasal carriage and staphylococcal diseases (Wertheim et al., 2005). Thenceforward, many studies confirmed this causal association by identifying the identical genotypes shared by both nasal and infecting *S. aureus* strains (Blomqvist et al., 2015; Corne et al., 2005; Eiff, 2001).

Colonization seems to be influenced by an intra-species competition with methicillin-sensitive *S. aureus* (MSSA) playing a protective role in the prevention of methicillin-resistant strains (MRSA) infections (Dall'Antonia et al., 2005). However, nasal carriers are not only at risk of acquiring endogenous or exogenous infections, they are also responsible for the spread of pathogenic strains to surrounding environments (Septimus & Schweizer, 2016). Indeed, during the handling of food, nasal carriers' hands represent the main vector for the dissemination of *S. aureus*, and poor personal hygiene is a leading cause of contamination (Ghasemzadeh-Moghaddam et al., 2015; Sakr et al., 2018). Hence, asymptomatic food handlers can contaminate food via manual contact or through respiratory secretions becoming the source of staphylococcal food poisoning (SFP) (M. Á. Argudín et al., 2010; Bencardino & Vitali, 2019; Leibler et al., 2016).

S. aureus can also colonize a wide range of animals, especially livestock. It is known that strains recovered from companion animals are similar to human strains, while those isolated from food animals are animal-adapted clones. Transmission among humans and companion/food animal strains was largely recovered (Pantosti, 2012). We believe this is another aspect that deserves consideration due to the wide number of employees on farms. Moreover, integration of companion animals in household, in particular in industrialized countries where this tendency is largely diffused, contributes to the diffusion of strains of animal origin to humans, and the related risk shouldn't be underestimated.

The emergence of community-acquired (CA)-MRSA infections in the last decades and the need to monitor antibiotic-resistant strains in the community have prompted many studies on handlers and its potential transmission to food. However, considering the risk associated with the spread and transmission by colonized healthy individuals, the number of studies remains still low. Focusing on this aspect could be very important to collect more information about, leading to an improved understanding of several aspects, firstly the mechanisms of colonization.

1.3. Staphylococcal foodborne poisoning

SFP is a gastrointestinal intoxication resulting from the ingestion of food contaminated by enterotoxin produced by *S. aureus* (M. Á. Argudín et al., 2010; Fisher et al., 2018). Enterotoxins can cross the gastrointestinal tract undisturbed thanks to their ability to evade proteolytic enzymes (Hait et al., 2014). Within the digestive tract, enterotoxins are resorbed into the blood triggering nausea and/or vomiting (Tang et al., 2011).

SFP is an acute illness characterized by a sudden onset of vomiting, nausea, abdominal cramping and diarrhea, and usually runs its course within 12–48 h. All of these symptoms can appear, with or without fever, within two to 8 h after the consumption of contaminated food (Argudín et al., 2010; Schelin et al., 2011; Sergelidis & Angelidis, 2017).

The main factors affecting the severity of the intoxication are the susceptibility of the subject and the amount of enterotoxins that were ingested. In the rare instances when hospitalization is required, the hospitalized subjects are usually infants, the elderly or debilitated patients and, approximately, 20–100 ng of preformed enterotoxins are sufficient to cause SFP (Argudín et al., 2010; Hennekinne et al., 2012; Sergelidis & Angelidis, 2017; Zhao et al., 2016).

In Europe, the number of SFP incidents is rising, as reported by *The European Union One Health 2018 Zoonoses Report* in 2019. In 2018, there were a total of 114 reported outbreaks caused by staphylococcal toxins, with 1124 human cases, but only 167 requiring hospitalization (Food & Authority, 2019). Remarkably, most individuals fully recover from the infection without seeking medical assistance, leading to the underestimation of the real incidence of SFP. However, though rare, the life-threatening cases of SFP represent a serious problem for both the food industry and healthcare systems (Fisher et al., 2018). Many staphylococci species have been recognized as responsible for SFP outbreaks; however, *S. aureus* is the main culprit (Hennekinne et al., 2012).

Various food matrices are commonly associated with SFP, but the most prevalent implicated foods are meat and meat products, poultry and egg products, unpasteurized milk and dairy products (Argudín et al., 2010). Salads, cream-filled bakery products, cakes and sandwich fillings are also involved in many SFP outbreaks because they are optimum growth media for *S. aureus* (Argudín et al., 2010; Hennekinne et al., 2012). After contamination, improper storage conditions allow *S. aureus* strains to grow and reach the cell density necessary to produce enterotoxins. Temperature, pH, water activity (a_w), oxygen, redox potential and salt concentration all affect growth and enterotoxin production. However, temperature is a critical factor because enterotoxins are resistant to heat treatment of traditional cooking making it useless in neutralizing contaminated food (Argudín et al., 2010; Hait et al., 2014; Schelin et al., 2011). *S. aureus* can grow over an optimum range of temperature extending from 35 °C to 41 °C, whereas the optimum temperature for the production of enterotoxins ranges from 34 °C to 40 °C (Schelin et al., 2011). Heat treatment for 60 min at 60 °C kills *S. aureus* cells while enterotoxins may persist, and they have increased stability if present at high concentrations (Necidová et al., 2019). Moreover, thermal resistance of SEs is also dependent on other factors such as food matrix, pH, NaCl and type of toxin. The heat treatments used in food processing are not effective to destroy the high levels of SEs usually responsible for an outbreak (Hennekinne et al., 2012). As reported by Necidová and colleagues, SEs are active after boiling for 30 min and may remain stable at 121 °C for 28 min. In addition, they persist after pasteurization of milk and can be destroyed only after sterilization of the product (Necidová et al., 2019). However, this condition destroys enterotoxins but is leading to the detriment of food and their nutritional values (Ciupescu et al., 2018; Schelin et al., 2011). In light of this, compliance with hygiene rules during processing becomes crucial, leading to reduce the potential presence of this pathogen and enterotoxins from the beginning of food processing. In order to achieve this goal, implementation of training programs for handlers involved in all phases of the food chain is necessary.

1.4. Staphylococcal enterotoxins

Preformed staphylococcal enterotoxins (SEs) belong to the *S. aureus* superantigen family, and the different serotypes of this species share similar protein structures and biological activity while antigenicity is the key feature that differentiates serotypes (Hait et al., 2014). To date, more than 20 superantigens have been described, from SEA to SEIV, including the toxic shock syndrome toxin-1 (TSST-1), originally designated SEF (Fisher et al., 2018; Pinchuk et al., 2010; Principato & Qian, 2014). Generally, SEs are carried by mobile genetic elements such as plasmids, transposons, prophages and pathogenicity islands.

Classical SEs, responsible for 95% of SFP cases, are classified as SEA, SEB, SEC_n (where n indicates the different serotypes SEC1,SEC2, SEC3, SEC ovine and SEC bovine variants), SED and SEE (M. Á. Argudín et al., 2010; Hennekinne et al., 2012; Pinchuk et al., 2010). Of these, SEA and SEB are the most common and, therefore, also the most thoroughly studied. SEA is strongly related to SFP and is also the most potent stimulator of T cells (Miron & Miron, 2010; Pinchuk et al., 2010). However, SEB is considered the most dangerous SE not only because of its ability to cause SFP after ingestion, but also because of its use in bioterrorism and warfare (Hnasko et al., 2019; Krakauer & Stiles, 2013).

On the other hand, nonclassical SEs have recently been described and named SEG, SEH, SEI, SER, SES and SET (Hennekinne et al., 2012). Of these, only SEG, SEH and SEI have been frequently reported in SFP outbreaks (Ikeda et al., 2005; Jørgensen et al., 2005; Machado et al., 2020, pp. 1–10). Furthermore, SE-like (SEl) enterotoxins have also been recognized as SElJ, SElK, SElL, SElM, SElN, SElO, SElP, SElQ, SElU,

SElU2 and SElV. Emetic activity has been confirmed for all of the SEs, with the exception of SEl (Hait et al., 2014; Lina et al., 2004). They have a domain involved in digestive toxicity and another domain that is important for super-antigenic activity, but it is not clear whether these two functions can be separated. Indeed, a perfect correlation between immunological and emetic activities is still not established (Miron & Miron, 2010). Their superantigenic activity allows toxins to enter the bloodstream, to interact with antigen-presenting cells. It is hypothesized that SEs effects are due to the superantigenic activity triggering intestinal inflammatory response and degranulation of intestinal mast cells (Kadariya et al., 2014; Principato & Qian, 2014). Toxins are clearly able to exert a wide range of activities within the digestive tract, but despite all efforts the precise role of superantigenic activity by which they trigger inflammatory response is still not understood. The production, enterotoxigenic mechanism and immunomodulatory function of SEs are regulated by a complex network of key elements, which are well described by Fisher and colleagues; however, many aspects of SEs are still not clearly understood (Fisher et al., 2018).

1.5. Aim of the review

To date, a large number of studies have reported the involvement of food handlers in food contamination (Alhashimi et al., 2017; Bencardino & Vitali, 2019; Castro et al., 2016; Rall et al., 2010). Previous published reviews have focused, individually, on fully describing *S. aureus* nasal carriage or specific aspects of SFP, such as the recording of outbreaks or enterotoxin production in different food (Brown et al., 2013; Ceccarelli et al., 2019; Frank et al., 2010; Kadariya et al., 2014; Pinchuk et al., 2010; Sakr et al., 2018). Our aim, on the other hand, was to explore the risk associated with nasal carriers during food processing, describing cross-contamination routes. Hence, we reviewed all investigations aimed to evaluate the carriage rate among food handlers and outbreaks caused by asymptomatic carriers. Finally, we described the significance of nasal decolonization, reporting the main antimicrobial agents currently used to treat carriers, and emphasized preventive strategies to limit the spread of this pathogen in food settings.

2. Methods

A literature search of studies published in the last twenty years was carried out in PubMed (https://pubmed.ncbi.nlm.nih.gov/), the largest available resource since 1996, accessed via the National Library of Medicine PubMed interface (Help et al., 2013, pp. 1–39). The keywords were: "*Staphylococcus aureus"* in combination (and) with "food handlers", "decolonization" or "immune response". Additional PubMed searches were performed using the keywords: "staphylococcal food poisoning", "food handlers and *S. aureus*", "food handlers and cross-contamination" and "*S. aureus* and nasal decolonization". In order to perform a complete literature search, no article type restrictions were applied.

The aim was to summarize the literature published over the past twenty years concerning the role of *S. aureus* carriage in SFP. Therefore, information about the relationship between the causative agent and the SFP, mechanism of infection, hand hygiene, contact surfaces, decolonization, surveillance and preventions strategies were all reviewed. Furthermore, the websites of the European Food Safety Authority (EFSA, https://www.efsa.europa.eu/), European Centre for Disease Prevention and Control (ECDC, https://www.ecdc.europa.eu/en) and Centers for Disease Control and Prevention (CDC, https://www.cdc.gov/) were examined to collect data about surveillance programs.

3. Nasal carriage

3.1. Classification of nasal carriers

Humans are frequently colonized by *S. aureus* for long or short periods at different stages in life (Brown et al., 2013; Sakr et al., 2018). A low percentage of neonates (5%) can be infected at birth, especially during a normal delivery through contact with maternal strains (Bourgeois-Nicolaos et al., 2010).

In general, colonization with maternal strains may occur in the first two weeks of life, disappearing by six months with the development of the immune system (Peacock et al., 2003). Transmission of the pathogen occurs exclusively after direct skin-to-skin contact or through contact with recently contaminated fomites, and host differences may confer colonization resistance (Brown et al., 2013). Commonly, carriers can be divided into two categories: persistent and intermittent nasal carriers. Approximately 20% of the global population is persistently colonized by a single genotype, whereas 30–50% of the population, so-called intermittent carriers, are frequently infected by different strains (Ritchie et al., 2016; Sakr et al., 2018). Although persistent carriers may acquire new strains, the replacement of these strains with their original colonizing genotype has been shown in many experimental studies (Nouwen, Boelens, et al., 2004; Van Belkum et al., 2009).

An accurate differentiation between persistent and intermittent carriers thus requires that nasal swabs be performed at different sampling times. As demonstrated by Nouwen and colleagues, the prediction of persistent carriage status can be obtained with 93.6% reliability by combining the qualitative and quantitative results of two nasal swabs (Nouwen, Boelens, et al., 2004). These findings support the use of screening of handlers for long periods of time aimed to evaluate the carriage status allowing, thus, the identification of potential persistent carriers. In addition, by sampling nasal carriage more frequently the efficacy of antibiotic therapy can be monitored collecting information about its possible failure.

3.2. Nasal colonization and interaction with microbiota

S. aureus colonizes both the epithelia of the anterior nares (vestibulum nasi) and the inner (internal nares) through adhesive molecules, such as Clumping factor B (ClfB) and iron-regulated surface determinant A (IsdA) (Burian et al., 2010; Clarke et al., 2004; Wertheim et al., 2008). These ligands interact with loricrin and cytokeratin 10, which are among the major proteins expressed by the keratinocytes of the cornified layer (Mulcahy et al., 2012).

Conversely, the colonization of the inner nasal cavity seems to be guided by a non-protein staphylococcal adhesion (cell wall teichoic acid, WTA) interacting with the F-type scavenger receptor (SREC-1) of the epithelial cells (Baur et al., 2014; Weidenmaier et al., 2004). WTA is important for the initial as well the late phase of colonization, while the surface proteins determine nasal persistence (Hanssen et al., 2017). Having a good knowledge of *S. aureus* location within the nasal cavity is extremely important to carry out the swab collection properly and thus obtain maximum sensitivity (Warnke et al., 2014).

Carriage status also affects the composition of the microbial community within the nasal cavity and *Corynebacterium accolens* and *Corynebacterium pseudodiphtheriticum* are the most prevalent determinants (Yan et al., 2013). The former seems to promote the growth, *in vitro,* of *S. aureus* as a consequence of a mutual adaption, whereas the latter has been shown to inhibit *S. aureus* (Frank et al., 2010; Lina et al., 2003). In fact, some bacterial species are able to produce anti-staphylococcal molecules that guide crucial inhibition mechanisms (Krismer et al., 2017). Among them, *Streptococcus pneumoniae* and *Staphylococcus lugdunensis* have been described as producers of bactericidal bioactive compounds, such as H_2O_2 and lugdunin, respectively (Selva et al., 2009; Zipperer et al., 2016). The prevalence of certain species in the mucosal sites of the nasal cavity is also favored by important environmental factors, such as humidity and moisture (Yan et al., 2013).

We conclude that an optimal relationship between host and microbial community colonizing the internal nasal cavity seems to be important. Further research and development of new strategies for the investigation of this relationship should be very useful to identify the specific host and bacterial factors involved.

3.3. Risk factors for colonization

Colonization rates depend on host features such as age, sex, ethnicity, socioeconomic status, antibiotic use, and underlying diseases, resulting in personalized carriage status. For example, the presence of underlying disorders represents an important predisposing factor for the acquisition of nasal carriage (Mattner et al., 2010; Sakr et al., 2018; Sollid et al., 2014; Van Belkum et al., 2009). Patients with human immunodeficiency virus (HIV) or skin and soft tissue infections, obesity and rheumatoid arthritis have a strong predisposition for nasal carriage (Immergluck et al., 2017; Kotpal et al., 2016; Laudien et al., 2010; Olsen et al., 2013). Genetic predisposition to nasal carriage does not appear to be inheritable, as shown by studies that enrolled members of the same family, including twins. In light of this, host genetic factors cannot be considered strong determinant of persistent nasal colonization (Roghmann et al., 2011). However, these studies were carried out testing small groups of twins at pediatric age, where colonization rate is different from adults. By contrast, studies carried out on adults revealed that genetic polymorphisms in immune response genes are strongly related to increased carriage status due to polymorphisms in genes encoding for the glucocorticoid receptor, interleukin-4, C-reactive proteins and complement inhibitor proteins (Emonts et al., 2008; Ruimy et al., 2010). Also in these studies, the cohort of tested individuals was small, but with low contact with the outside of the world suggesting that the high colonization rate, caused by a dominant strain, could be due to host genetic polymorphisms rather than epidemiological factors (Ruimy et al., 2010). Taken together, these results highlight the need of further and wider investigations to confirm or refute this finding. If host genetic factors will be confirmed as strong determinants for nasal colonization, the human carriage could be better monitored. Importantly, nasal colonization represents a crucial risk factor for the acquisition of infections in both private and nosocomial infections (Sakr et al., 2018; Warnke et al., 2014). The spread of *S. aureus* from the nose to the skin can increase the likelihood of surgical wound infection, especially in orthopedic and cardiac surgery settings (Lepelletier et al., 2005; Muñoz et al., 2008). The occurrence of infections has also been evaluated in nonsurgical patients screened for nasal carriage confirming the related risk (Eiff, 2001; Honda et al., 2010). The potential route for *S. aureus* transmission includes not only patients but also family members and health-care workers (Denis, 2017). Likewise, the possible transmission of *S. aureus* strains by healthy individuals is also a matter of concern in the food service sector and food industries (Alhashimi et al., 2017; Castro et al., 2016a; Schelin et al., 2011). In both cases, the identification of the contamination sources is crucial to putting in place suitable control measures.

The present review highlights the crucial role played by host factors in determining the *S. aureus* nasal carriage status in healthy adults. Additional genetic and functional studies in large populations are warranted to further clarify the contribution of these individual factors to staphylococcal nasal carriage and infections in humans.

4. Food handlers and cross-contamination

4.1. Spread and transmission of *S. aureus*

Cross-contamination has been identified as one of the causes of SFP resulting in microbial transfer to food from other foods and/or non-food elements, including surfaces and workers (Kadariya et al., 2014). Food handlers carrying *S. aureus* in their nose can contaminate their hands and other parts of their body, acting as a major source of cross-contamination at any stage of the food production, processing and distribution chain (Colombari et al., 2007). Moreover, poor personal hygiene practices on the part of handlers can have serious effects on food safety favoring the dissemination of *S. aureus* strains during production, processing and distribution (Al-Bahry et al., 2014; Greig et al., 2007).

Dynamic interactions between handlers, foods and contact-surfaces allow the spread of the pathogen in food industry settings. In general, *S. aureus* strains are likely to be transmitted by handlers to foods through improper handling and respiratory secretions (Al-Bahry et al., 2014; Castro et al., 2016a; El-Zamkan et al., 2019).

To prevent the spread of several pathogens, including *S. aureus*, hand washing with soap and water is the most important practice. If soap and water are not available, an ethanol alcohol-based hand sanitizer (60% of ethanol) is strongly recommended, preferably in a gel form (Centers for Disease Control and Prevention (CDC), 2015). Notwithstanding the limited number of studies that have been carried out on gloves, the proper use of disposable gloves has been recognized as an effective method to minimize the transfer of contaminants from bare hands to foods (Lynch et al., 2005; R.; Montville et al., 2001).

Yap and colleagues showed that handling sushi and its related ingredients with gloves rather than bare hands lowered the risk of contamination. In addition, the combination of frequent glove changing and hand washing resulted in much lower levels of cross-contamination (Yap et al., 2019). By contrast, the tendency of workers to use the same gloves for a long time or to wash their hands less frequently reduced the effectiveness of these practice, increasing the risk of contamination (Lynch et al., 2005). Notably, gloves reduce the transfer of bacteria from the hands to foods and *vice versa* preventing another serious route of cross-contamination (R. Montville et al., 2001). In short, proper hand washing followed by frequent glove changing could be helpful to reduce the risk of contamination.

Moreover, CA-MRSA infections also spread among healthy individuals by skin-to-skin contact and fomites such as towels, sheets and equipment (Mediavilla et al., 2012; Scott et al., 2008). The spread of *S. aureus* infections among persons dwelling in the community is strongly associated with transmission in households via fomites and hand-contact surfaces fostered by poor hygienic practices which increase the risk of SFP outbreaks (Miller et al., 2015; Scott et al., 2008; Turabelidze et al., 2006). Hence, a better knowledge of the risks related to the improper handling of food products by *S. aureus* carriers is essential to avoid this potential source of contamination in the food service sector and the food industries.

Food handlers working in the same area of an industrial plant may have close physical contact with one another and shared objects, increasing the risk of contamination. To date, these routes of transmission among food handlers have not been investigated. This lack of research is probably due to the complicated process of implementing contact tracing in large groups of workers, who are also in contact with other people, including family members.

4.2. Survival on surfaces and materials

Indeed, the ability of *S. aureus* to attach on food contact surfaces promotes the production of biofilm in food settings. After initial attachment, cells start to multiply secreting a matrix of extracellular polymeric substances useful not only to embed environmental nutrients but also to enhance the tolerance to disinfectants (Archer et al., 2011). For this reason, adhesion and biofilm represent important virulence factors that allow *S. aureus* to survive on different surfaces promoting the colonization of hostile environments, thereby increase the risk of cross-contamination recurrence (Galié et al., 2018; Gutiérrez et al., 2012).

Noteworthy, all food processing conditions characterized by both temperature and use of those nutrients optimal for bacterial growth promote the survival of diversified microbial communities that include several food pathogens. The presence of *S. aureus* in mixed-species biofilms could enhance its colonization and persistence in food settings stressing the need to improve hygienic measures (Gutiérrez et al., 2012). Usually, *S. aureus* exhibits a good level of adhesion on many types of inert surfaces, especially on stainless steel that is largely employed in food industry. Moreover, roughness, wettability and energy surface are considered the most important features to promote the adhesion (Alam & Balani, 2017; Hamadi et al., 2014).

To facilitate risk management, all of the potential events of cross-contamination need to be evaluated thoroughly. In the last few years, many mathematical models illustrating contamination routes as well as the reduction of different microorganisms have been published (Mokhtari & Jaykus, 2009; Rebecca Montville et al., 2002; Pérez-Rodríguez et al., 2006, 2008).

Arinder et al. (2016) evaluated the transfer rate of *S. aureus* using an artificial skin to simulate the real exposure of human subjects to the pathogen. They observed higher levels of transfer rates from inoculated artificial skin to fomites than from inoculated fomites to skin confirming the important role of the latter in spreading bacteria. The authors also showed how one contaminated hand can infect an inanimate surface which in turn can also be responsible for the infection of other hands (Arinder et al., 2016).

Hence, hand washing plays a pivotal role in controlling *S. aureus* transfer whether from person to person, from person to food, or from person to surfaces (Chinakwe, 2012, pp. 144–146). Satisfactory hand hygiene among food handlers is a critical good practice that can limit the spread of SFP (Lambrechts et al., 2014).

We strongly believe that hygiene of production environment, including handlers and contact surfaces, play a pivotal role in reduction of cross-contamination risk. Another important aspect, often underestimated, is the lack of training in handlers involved in cleaning and disinfection of areas dedicated to production, processing, storage and distribution of food. Studies aimed to evaluate the knowledge of these handlers should be very interesting to determine their contribution to the increase of risk associated with food contamination through surfaces and utensils.

5. Staphylococcal food poisoning caused by handlers

5.1. Prevalence of nasal carriers in food settings

In order to investigate the role of *S. aureus,* which colonizes and infects humans, as a potential source of SFP, Wattinger and colleagues compared isolates associated with SFP and those collected from both human nasal carriers and clinical infections. For this purpose, the authors considered isolates collected from the nasal swabs of healthy donors, human clinical infections and SFP cases. This investigation revealed 37.6% of nasal carriers, with the prevalence of genes encoding for enterotoxin A. All isolates were characterized by Spa typing and DNA microarray profiling showing highly similar virulence profiles. This finding confirmed the potential risk of food contamination by *S. aureus* colonizing and infecting food handlers (Wattinger et al., 2012).

In light of this finding, an increasing number of surveillance programs have been implemented in several food service and industrial production, processing and distribution settings, stressing the importance of screening and treating handlers as a useful strategy to avoid outbreaks. For example, a cross-sectional study carried out by Simsek and colleagues revealed a carriage rate in 23.1% of handlers randomly selected, and half of them had not been previously screened. In this study, strains were not characterized in terms of toxin detection (Simsek et al., 2009).

Hatakka and colleagues detected 29% prevalence of nasal carriers among workers at a flight-catering plant in Finland; 46% of the strains were enterotoxigenic and the predominant enterotoxin was the type B. In many cases, the same strain was isolated from both the nose and hands of the same handler, and different employees were colonized by the same genotype. The mass-catering setting is well known to be at high-risk due to the fact that several steps require the manual handling of catered food, and the presence of carriers highlights the potential risk associated with cross-contamination (Hatakka et al., 2000).

Similar trends of nasal carriage rates have also been observed in Brazil, where the prevalence among the employees of a dairy product processing plant was 35.2%. In addition, similar genotypes were found among strains isolated from different sources including a food handler at the plant (Tondo et al., 2000).

Nasal carriage mediated by *S. aureus* enterotoxin-producing strains raises the potential health hazard associated with cross-contamination caused by improper handling. In many cases, handlers presented strains encoding even more enterotoxin genes (Aung et al., 2017; Castro et al., 2016; Da Silva et al., 2015; Fooladvand et al., 2019; Osman et al., 2019), with the prevalence of SEA (Argudín et al., 2012; Figueroa et al., 2002; Jordá et al., 2012; Loeto et al., 2007; Rall et al., 2010) followed by SEB (Brizzio et al., 2011). For instance, Loeto and colleagues evaluated 200 handlers among different institutions in Botswana detecting 44.6% nasal carriers and the most prevalent toxin was the type A (Loeto et al., 2007). Brizzio and colleagues described an outbreak occurred in 2008, in Argentina, caused by the consumption of vegetable cannelloni bought in a local shop. Nasal carriage was found to be 2%, and enterotoxin B was detected in strains isolated from a food handler as well as from the contaminated food (Brizzio et al., 2011).

Investigations concerning the screening of nasal carriers within food settings are increasing, but surveillance programs of handler should be strongly recommended in order to collect more information about the epidemiology and colonization mechanisms. The availability of these data could be very useful to further clarify these aspects and also to enable the implementation of control and preventive measures.

5.2. Overview of outbreaks caused by handlers

In the last two decades, numerous studies have investigated the prevalence of carriers among food handlers. Given the use of disinfectants during work shifts, assessing *S. aureus* carriage only by examining hands is not a reliable approach. By contrast, the nasal swab is a good way to detect carriers of *S. aureus* among food handlers (Hatakka et al., 2000).

We reviewed all investigations carried out on nasal carriers working in different food service and industrial production, processing and distribution settings, and the results are summarized in Table 1. The overall nasal carriage rate shows variations across studies carried out since 2000. However, most studies reported a nasal carriage rate between 20% and 50% (Hatakka et al., 2000; Loeto et al., 2007; Simsek et al., 2009; Wattinger et al., 2012). Only a few studies reported a low rate (2–7%) (Brizzio et al., 2011; Ercoli et al., 2017; López et al., 2008). Notably, more than 50% of handlers were identified as nasal carriers in a growing number of investigations highlighting the importance of monitoring (Gündüz et al., 2008; Manfredi & Rivas, 2019; Nasrolahei et al., 2017; Saeed & Hamid, 2010; Udo et al., 2009; Wei et al., 2014).

Over the past 20 years, several SFP outbreaks have reportedly been caused by asymptomatic workers. In all of these cases, the origin of the SFP outbreaks was associated with contamination caused by food handlers, who were linked to the contamination by comparative analyses (Table 2).

In May of 2000, ten students at a high school in Taiwan developed SFP symptoms after consuming salad croutons baked at local bakery. Genotyping analyses were carried out using pulsed-field gel electrophoresis (PFGE), inter-IS256 PCR typing, protein A gene (spa) typing, and coagulase gene restriction profile (CRP) in order to characterize strains. PFGE results revealed that the strain isolated from the hand wound of a food handler responsible for the contaminated salad preparation was the same as the strains isolated from patients, suggesting that the outbreak originated from the food handler (H. L. Wei & Chiou, 2002).

In another study carried out in 2006, 150 people who took part in a popular festival in Argentina displayed SFP symptoms. Microbiological analyses and subsequent typing through PFGE detected *S. aureus* strains in a piece of cake that were similar to those isolated from a food handler linking the origin of the outbreak to improper hygienic conditions in the

Table 1
Prevalence of nasal carriers in different food settings between 2000 and 2020.

Location	Food setting	Prevalence[a]	Reference
Capital area in Finland	Flight-catering	111; (29%)	Hatakka et al. (2000)
Nova Petropolis, Brazil	Dairy-processing plant	51; (35.2%)	Tondo et al. (2000)
Santiago, Chile	Restaurants	102; (19%)	Figueroa et al. (2002)
Taichung County, Taiwan	High school handlers	–	Wei and Chiou (2002)
Gaborone, Botswana	Different food institutions	200; (44.6%)	Loeto et al. (2007)
Manisa, Turkey	Restaurants and cafeterias	8895; (85.2%)	Gündüz et al. (2008)
Neuquén, Argentina	Food preparation and service	-; (3%)	López et al. (2008)
Sanliurfa, Southeastern Anatolia	Bakeries, restaurants and butcher shops	299; (21.2%)	Simsek et al. (2009)
Kuwait City, Kuwait	Restaurants	250; (53.2%)	Udo et al. (2009)
The Netherlands	Meat handlers	89; (35%)	de Jonge et al. (2010)
Botucatu, Brazil	Industrial kitchens	82; (22.1%)	Rall et al. (2010)
Omdurman Area of Sudan	Restaurants, bakeries, store-keepers, milk distributors, butchers and fruit/vegetable sellers	259; (71.8%)	Saeed and Hamid (2010)
Las Rosas, Argentina	Local shop	-; (2%)	Brizzio et al. (2011)
Switzerland	Healthy donors	133; (37.6%)	Wattinger et al. (2012)
Asturias, Spain	Restaurants	–	Argudín et al. (2012)
Gondar University, Ethiopia	Cafeterias	200; (20.5%)	Dagnew et al. (2012)
Province of Misiones, Argentina	Restaurants	88; (37.5%)	Jordá et al. (2012)
China	Catering establishments	434; (22.8%)	Ho et al. (2014)
Taiwan	Bakery	20; (65%)	Wei et al. (2014)
Natal, Brazil	University Restaurant	30; (93.3%)	Da Silva et al. (2015)
Kars, Turkey	Catering services	28; (35.7%)	Vatansever et al. (2016)
Portugal	Food company	162; (19.8%)	Castro et al. (2016)
Botucatu City, Brazil	Industrial kitchen	-; (17%)	Baptista et al., 2016
Italy	Cooks and waiters	-; (5%)	Ercoli et al. (2017)
Sari City, Iran	Different food establishments	220; (65.4%)	Nasrolahei et al. (2017)
Belgium	Kitchen handlers	–	Denayer et al. (2017)
Myanmar, Southeast Asia	Kitchen and wait staff	563; (19.5%)	Aung et al. (2017)
Italy	Pasta company	21; (33%)	Bencardino and Vitali (2019)
Jimma Town, Ethiopia	Hotels and restaurants	300; (9%)	Beyene et al. (2019)
Qena City, Egypt	Hospital food handlers	30; (23.3%)	El-Zamkan et al. (2019)
Arak, Iran	–	1113; (20.1%)	Fooladvand et al. (2019)
Tripoli, Lebanon	Pastry	160; (23.8%)	Osman et al. (2019)
District of Hurlingham, Province of Buenos Aires	Handlers of a kindergarten	5; (60%)	Manfredi and Rivas (2019)
Germany	Cooks, butchers and meat sellers	605; (21.5%)	Cuny et al. (2019)
Çanakkale, Turkey	Business and hospital kitchen employees	300; (41.6%)	Çakici et al., 2019
Morocco	Hospital kitchen	30; (33.3%)	Benjelloun Touimi et al. (2020)

- data not provided by the authors of the study.
[a] Prevalence was reported as the number of screened individuals followed by the percentage of positive.

Table 2
Overview of SFP outbreaks caused by handlers and molecular typing of isolates.

Outbreak description	Genotyping analyses	Epidemiological investigation	Reference
- high school setting; - 10 affected students; - Taiwan, 2000;	- PFGE; - inter-IS256 PCR typing; - spa typing; - (CRP) analysis;	Two strains with the same PFGE profile were isolated from patients and a hand lesion of a food handler.	Wei and Chiou (2002)
- lunch held during a popular feast; - 150 affected local residents; - Argentina, 2006;	- enterotoxin gene typing; - PFGE;	Strains isolated from both the cake and one of the food handlers carried the *sea* gene, and presented the same PFGE pattern.	López et al. (2008)
- Online shop; - 32 out of 866 consumers were affected; - Taiwan, 2010;	- PFGE;	Strains isolated in 13 food handlers shared the same PFGE profile of those detected in the contaminated food.	Wei et al. (2014)
- kindergarten class; - 6 children affected; - Belgium, 2013;	- enterotoxin gene typing; - PFGE;	Strains isolated from patients, contaminated food and a handler showed an identical pulsotype.	Denayer et al. (2017)
- restaurant; - 24 customers were affected; - Italy, 2015;	- enterotoxin gene typing; - PFGE;	Three *sea*-positive strains isolated from the dessert, environment, and a cook, had the same PFGE profile.	Ercoli et al. (2017)
- chicken salad consumed in a kindergarten; - 37 children and 10 adults affected; - Argentina, 2008;	- enterotoxin gene typing; - PFGE;	Strains isolated from food, stool specimens of patients, and 3 food handlers carried the same enterotoxin genes and PFGE patterns.	Manfredi and Rivas (2019)

cake preparation (López et al., 2008).

In 2008, consumption of contaminated chicken salad in a kindergarten in the Province of Buenos Aires caused a foodborne outbreak. *S. aureus* was isolated from patients and three out of five food handlers. All the isolates carried genes encoding for SEA and SED enterotoxins and shared 100% similarity in terms of PFGE patterns, highlighting failures in food processing practices (Manfredi & Rivas, 2019).

An emerging business with serious food safety risks is the sale of food online. In Taiwan (2010), a nationwide foodborne disease outbreak was reportedly caused by sandwiches purchased online. *S. aureus* was isolated in 13 out of 14 nasal swabs taken in food handlers. The strains isolated from the swabs were also detected in the contaminated food (S. H. Wei et al., 2014). PFGE typing revealed a common origin of *S. aureus* strains isolated from food and a worker.

Three SFP outbreaks occurred in Belgium in 2013. One was associated with a residential facility for the elderly (28 cases), another with a barbecue event (18 cases) and a third occurred in a kindergarten class (6 cases). Molecular typing of human and food isolates confirmed the relationship between the patients and the contaminated food, including potatoes where high amounts of *S. aureus* sea-producing strains were detected. Only for the outbreak occurred in kindergarten class, PFGE revealed one of the handlers as responsible for food contamination. Strains isolated from the human cases and that isolated from contaminated food showed an identical pulsotype. Moreover, also the strain isolated from the nanny showed the same pulsotype revealing the possible transmission of the strain through her (Denayer et al., 2017).

In 2015, a SFP outbreak occurred in Italy (Umbria Region) affecting 24 restaurant customers. High levels of SEA were detected in the Chantilly cream dessert, and five food handlers were positive for *S. aureus*. In particular, the three *sea*-positive strains isolated from the dessert, the restaurant environment, and a cook, had the same PFGE profile and belonged to a human biotype, suggesting that a food handler was responsible for the outbreak (Ercoli et al., 2017).

All of these studies confirmed the screening of handlers as an important tool to monitor the presence of nasal carriers among them and also to reduce the risk of cross-contamination. Implementation of these programs could be very useful not only for food safety but also to reduce the transmission of *S. aureus* strains in the community decreasing, for instance, the risk related to CA-MRSA infections. Moreover, investigations of food-borne outbreaks require a well-coordinated approach and a multidisciplinary team that brings together experts from animal and human health sciences, but also epidemiologists and food microbiologists.

5.3. Exposure to raw meat as risk for colonization

Although food, especially raw meat, can be a vehicle for *S. aureus*, there is limited variable data in the literature on the real risk of colonization through the handling or consumption of raw meat. The work of De Jonge and colleagues, carried out in 2010, showed that the risk of colonization through contact with raw meat for handlers is very low. Because members of a community come into contact with raw meat more rarely than handlers, who touch it many times every day, the risk for consumers should be at most, equal to, if not lower, than the risk for workers (de Jonge et al., 2010).

Four years later, however, a report, which sampled handlers from six catering companies, found an increased risk associated with exposition to raw meat (Ho et al., 2014). Other studies have subsequently provided evidence supporting raw meat as a food matrix responsible for the transmission of *S. aureus* to handlers. Researchers investigated genotypic profiles of strains isolated from food samples and handlers finding a very high level of similarity between the profiles, suggesting a common animal origin (Baptista et al., 2016; Cuny et al., 2019; El Bayomi et al., 2016; Jackson et al., 2013; Larsen et al., 2016).

In our opinion, studies evaluating the risk related to exposure to raw meat as risk for colonization are increasing, but still scarce. Further investigations are required to fill the gap in literature and collect sufficient information to confirm the potential role of raw meat in the transmission of *S. aureus* to handlers.

5.4. Screening of food handlers

These findings show that food handlers play a key role in the spread of SFP emphasizing the need for the implementation of preventive measures or the strengthening of existing monitoring programs to control the spread of SFP in food establishments (Nasrolahei et al., 2017; Saeed & Hamid, 2010; Çakici et al., 2019). Several cross-sectional studies highlight not only the importance of screening and treating food handlers, but also the importance of regular training in hygiene practices (Dagnew et al., 2012; Ifeadike et al., 2012; Vatansever et al., 2016).

Moreover, strains with animal origins show a high level of antibiotic-resistance and handlers colonized by MRSA pose a serious threat in terms of community spread. Evidence provided by several studies reveals that strains isolated from food handlers at restaurants show high levels of antibiotic-resistance like MRSA strains isolated in hospital patients (Beyene et al., 2019; Udo et al., 2009).

The study carried out by Udo and colleagues reported the prevalence of 71.0% of isolates positive for SEs, and the most common enterotoxin was SEI (38.5%), confirming the importance of screening of food handlers to protect restaurant customers from SFP (Udo et al., 2009).

It is noteworthy that resistant strains are frequently detected in food establishments. Surveillance programs need to be implemented to monitor their spread. In an Italian surveillance program carried out in a pasta factory, 64% of the strains isolated from nasal carriers were found to be resistant to linezolid, confirming the rapid spread of resistance to this last resort drug that has been reported in the last few years (Bencardino & Vitali, 2019).

It is also known that food handlers play a crucial role in the transmission of MRSA and vancomycin-resistant *S. aureus* (VRSA) to hospitalized patients (El-Zamkan et al., 2019), and the spread of these strains in hospital environment has been proven by their detection on surfaces and food samples. Consumption of food contaminated by antibiotic-resistant *S. aureus* strains are a serious threat for the health of individuals affected by illnesses or with compromised immune system like hospital patients (Benjelloun Touimi et al., 2020).

6. Nasal decolonization and prevention

6.1. Mupirocin ointment

Nasal decolonization is the most important strategy to prevent *S. aureus* transmission and infections in some situations including food settings (Levy et al., 2013; Sakr et al., 2019; Septimus & Schweizer, 2016). There are several anti-staphylococcal agents for the eradication of both MSSA and MRSA, but mupirocin is currently considered the gold standard. It is a topical antibiotic, naturally produced by *Pseudomonas fluorescens*, with an excellent *in vitro* activity also against some streptococci (Sakr et al., 2019).

The clinical efficacy of mupirocin has been assessed in many studies involving surgical and nonsurgical patients, and it reaches 90–94% clinical efficacy after it is applied twice daily for four to seven days in the anterior nares (Ammerlaan et al., 2009; Sakr et al., 2019). However, treatment failure can occur due to several factors, such as extra-nasal carriage, recolonization from other sources or poor compliance (Ammerlaan et al., 2009; Bagge et al., 2019; Hansen et al., 2007).

On the other hand, the prolonged use of mupirocin raises mupirocin resistance levels, compromising the nasal decolonization of carriers (Caffrey et al., 2010). It is known that high-levels of mupirocin resistance can be mediated by the *mupA* gene located on plasmids and by the recently described *mupB* locus, and they are strongly associated with decolonization failure (Poovelikunnel et al., 2015). By contrast, low-levels of resistance are responsible for failure only if combined with genotypic chlorhexidine resistance (Fritz et al., 2013).

In light of these limitations, many efforts are currently focused on testing the efficacy of novel decolonization agents. For example, oral antibiotics are frequently used to treat patients colonized at multiple sites, but they are not recommended in patients without infections (Sakr et al., 2019). Decolonization treatments often combine topical nasal antibiotics and antiseptic drugs showing an increased efficacy. The concomitant use of mupirocin with chlorhexidine gluconate (CHG) seems to reduce the incidence of MRSA acquisition (Kim et al., 2016). However, chlorhexidine resistance, conferred by *qacA/B* and *smr* genes, combined with mupirocin resistance can lead to decolonization failure (Lee et al., 2011). On the other hand, a retrospective study showed that CHG bathing supplemented with nasal ointment of povidone-iodine reduces the infection incidence in surgical patients (Urias et al., 2018). Povidone-iodine is a broad-spectrum antibacterial known to be a topical preoperative antiseptic able to reduce antimicrobials on skin and anterior nares (Anderson et al., 2015). Taken together, these findings highlight the role of povidone-iodine as a valid alternative to mupirocin (Sakr et al., 2019).

Despite the large number of decolonization agents recently tested to treat nasal carriers, mupirocin remains the gold standard. However, the development of mupirocin resistance is a serious concern, and the discovery of new molecules require many efforts and in a short time. Several recommendations must be given and applied to ensure the adequate use of mupirocin in order to reduce the risk of resistance.

6.2. Novel decolonization agents

New molecules are also being investigated but their potential role as antimicrobial agents still needs to be evaluated, in particular, in terms of their efficacy. Of these molecules, Lysostaphin (an antibacterial enzyme able to act on the staphylococcal cell wall), Luminaderm (NP108, an antimicrobial peptide) and Epidermicin NI01 (a bacteriocin with activity on Gram-positive) seem to be more effective than mupirocin in rat models, but no clinical trials are available in humans (Halliwell et al., 2017; Kokai-Kun et al., 2003; Mercer et al., 2017).

The latest advances in the study of plant-derived natural products proved their efficacy as antimicrobial agents. Examples of these are terpenoids, flavonoids and organosulfur compounds. Terpinen-4-ol, the most abundant substance in tea tree essential oil, is a phytoconstituent with bactericidal activity against *S. aureus.* Probably, its efficacy is due to the ability to interfere with the cell wall synthesis demonstrating promising effects to treat *S. aureus* infections alone or in combination with other drugs (Cordeiro et al., 2020). Also thymol and carvacrol are two phenolic terpenoids that exert a relevant antimicrobial activity against *S. aureus;* both are obtained from essential oils, mainly from thyme and oregano (Sousa Silveira et al., 2020).

Moreover, flavonoids are bioactive compounds with strong antibacterial activity against several species and low toxicity toward mammalian cells (Adamczak et al., 2019). Usually, flavonoids are more effective against Gram-negative than Gram-positive with the exception of *S. aureus*. For example, glabrol and licochalcones from licorice showed antibacterial effects against MRSA (Wu et al., 2019), and the flavonoids in Citrox are widely described as effective to treat *S. aureus* strains able to produce biofilm (Hogan et al., 2016).

Among the wide panel of natural compounds promising beneficial effects on infections, allicin showed bactericidal activity inhibiting thiol-containing enzymes in bacterial cells. Recently, allicin received more attention not only for the antibacterial activity but also for its anti-virulence property and the use of allicin could be promising to treat α-toxin-producing *S. aureus* infections (Leng et al., 2011). However, further research investigating the efficacy of natural molecules should be strongly encouraged because their systematic use would avoid the selection of resistant strains. For example, tea tree oil and honey are known to have antibacterial activity, but their efficacy in nasal decolonization has not yet been clearly shown (Sakr et al., 2019).

6.3. Preventive measures

SFP could be prevented by avoiding cross-contamination and maintaining the cold chain as well as by screening food handlers (Kadariya et al., 2014). As demonstrated in a previous study, a regular carriage status monitoring of food handlers, especially for new recruit, could be a very important tool to preserve the safety of the product. Twenty-one handlers were sampled in a pasta company between 2013 and 2015 through nasal and hand swabs. The carrier-handlers were subjected to a treatment with the antibiotic mupirocin as described by the HACCP (Hazard analysis and critical control points) plan of the company. The 33% were contaminated with *S. aureus* and the prevalence decreased to 9.5% over the last year detecting only two persistent carriers (Bencardino & Vitali, 2019).

This strategy, supported by the monitoring of hygienic measures applied by handlers during their activity, prevent the occurrence of cross-contamination. The promptly identification of carriers followed by the application of nasal decolonization could be a useful approach to limit the spread and preserve food safety. Moreover, the possibility to identify carriers before they infect healthy colleagues reduces the number of people to be treated with antibiotics, decreasing, in turn, the risk related to resistance. Prevention is crucial not only in food service and industrial production, processing and distribution settings but also in domestic kitchens; hence, consumers need a comprehensive knowledge of the related risks. Health education programs targeting populations could be very useful to reduce the incidence of SFP outbreaks (Byrd-Bredbenner et al., 2013). In food service and industrial settings, unlike domestic kitchens, preventive measures should include the screening and treatment of handlers as well as training programs on hygiene practices such as appropriate hand washing (Dagnew et al., 2012; Ifeadike et al., 2012; Vatansever et al., 2016).

Other preventive measures that are proven to be effective include rapid serving of food kept at room temperature, maintaining the cold chain, the wearing of gloves and masks as well as hairnets during food processing (Kadariya et al., 2014). In industrial settings, the application of control measures from farm to fork, as well as adequate cleaning and disinfection of both utensils and surfaces are highly recommended (Hennekinne et al., 2012). In addition, we highlight the important role of Good Manufacturing Practices (GMPs) and Good Hygiene Practices (GHPs), the guidelines of systematic approaches such as Hazard Analysis and Critical Control Points (HACCP) that should be strictly observed to prevent SFP (Kadariya et al., 2014).

7. Conclusions

SFP is one of the most common foodborne diseases, and it represents a serious public health concern worldwide. Many studies confirm improper handling as an important cause of food contamination, and the presence of nasal carriers among healthy food handlers increases the contamination risk. This review provided a comprehensive overview of the relationship between nasal carriers and SFP in order to focus attention on the figure of the healthy carrier in food settings. Analyzing the data collected in all of the investigations carried out over the last two decades, we can identify several critical areas in the food service and production, processing and distribution industries that must be addressed, namely the lack of screening programs for food handlers, poor hygiene measures and the failure to maintain the cold chain of food products. Antibiotic treatment of nasal carriers is an important way to reduce and control the spread of *S. aureus*, and mupirocin is currently considered the gold standard for the treatment of these carriers. However, resistance mechanisms have compromised its effectiveness and other antimicrobial agents are now under evaluation. In any case, the implementation of preventive actions could be an important strategy to avoid or reduce cross-contamination of food by healthy workers carrying *S. aureus.*

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