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Methicillin Resistant Staphylococcus aureus and public fomites: a review

Ziad W Jaradat[a], Qutaiba O Ababneh[a], Sherin T Sha'aban[b], Ayesha A Alkofahi[b], Duaa Assaleh[b] and Anan Al Shara[b]

[a]Jordan University of Science and Technology, Irbid, 22110, Jordan; [b]Department of Applied Biological Sciences, Jordan University of Science and Technology, Irbid, 22110, Jordan

ABSTRACT

Staphylococcus genus is a Gram-positive coccus normally associated with skin and mucous membranes of warm-blooded animals. It is part of the commensal human microflora, or found in animals, or contaminating surfaces in the community and hospital settings. *Staphylococcus aureus* is the most pathogenic species belonging to this genus, as it possesses a collection of virulence factors that are expressed solely to evade the immune system. The increase in the misuse of antimicrobial agents predisposed *S. aureus* to develop antibiotic resistance, including the resistance to methicillin which led to the emergence of Methicillin-Resistant *S. aureus* (MRSA). MRSA is considered one of the most dangerous nosocomial pathogens causing many hard to treat infections in hospitals and was named as Hospital Associated MRSA (HA-MRSA). Over the past 20–25 years, MRSA was isolated from community settings and thus Community Associated MRSA (CA-MRSA) has emerged. Inside hospitals, MRSA has been isolated from fomites in contact with patients, as well as staff's protective and personal items. This review highlights the worldwide prevalence of MRSA on fomites within the contexts of hospital and community settings.

KEYWORDS
Methicillin resistance; *Staphylococcus aureus*; public fomites; Hospital Associated; Community Associated; review

Introduction

Staphylococcus species are Gram-positive, non-motile, non-spore forming microorganisms. *S. aureus* is the most pathogenic strain among this species with a potential to cause a wide range of diseases both in communities and hospitals [1].

As a commensal microbe, *S. aureus* mainly colonizes the nasal cavity of humans and many animals [2]. In addition, *S. aureus* is found on the skin, inside oral cavity, upper respiratory tract, lower urogenital tract, and gastrointestinal tract of humans [3]. In fact, 25–30% of people are permanently colonized with *S. aureus* and about 60% of the population are transiently colonized with this pathogen [4].

S. aureus possesses several virulence factors that allow the pathogen to thrive in diverse host environments and to survive extreme conditions [5]. *S. aureus* produces a set of cell-surface and secreted virulence factors such as enterotoxins and hemolysins which play a role in enhancing its pathogenicity [5,6]. Due to its wide distribution in the environment surrounding humans, *S. aureus* is considered one of the most harmful human pathogens implicated in several diseases ranging from mild skin-related infections to more severe life-threatening and systemic infections, such as bacteremia [3,7,8].

S. aureus was one of the first pathogens to develop resistance to penicillin shortly after its introduction [9]. In 1959, a new semi-synthetic β-lactam antibiotic, called methicillin was introduced to replace penicillin. However, only 2 years after its first use (1961), several cases of *S. aureus* strains resistant to methicillin were reported. These strains were also found to be resistant to other β-lactam antibiotics including oxacillin, cefoxitin, and other antibiotic families. Later, strains with this spectrum of resistance were given the name, methicillin-resistant *Staphylococcus aureus* (MRSA) [10,11].

Resistance to methicillin in *S. aureus* is primarily mediated by *mecA* gene carried on a mobile genetic element called staphylococcal chromosomal cassette (SCCmec) which is highly diverse and is classified into 13 types [12]. The *mecA* gene encodes a modified, low-affinity penicillin-binding protein (PBP2′), which confers cross-resistance to almost all β-lactam antibiotics [9,13].

Traditionally, MRSA has been considered a nosocomial pathogen responsible for health-care-associated (HA-MRSA) infections in patients, hospital personnel, and their associates [14]. However, the 1990s marked the emergence of MRSA within households as well as community facilities such as schools, daycares, geriatric homes, prisons, recreation centers, and many other institutions or settings [14,15].

Over the years, scientists have identified certain *S. aureus* lineages to be more prevalent in certain geographic areas. These linages are circulating all

CONTACT Ziad W Jaradat jaradatz@just.edu.jo Department of Biotechnology and Genetic Engineering, Jordan University of Science and Technology, P. O Box 3030, Irbid, Jordan

over the globe. Therefore, they were named so that they can easily be tracked. These lineages include the clonal complex 5 (CC5)/USA100, CC30/USA200, CC8/USA300, CC1/USA400, and CC45/USA600 [16]. Each lineage is endemic in a certain area; for example, *S. aureus* USA 100 is prevalent in the USA, both in health and community settings. *S. aureus* USA 400 is community-associated and is predominant in southern Alaska [16]. Further, several other lineages were detected in other parts of the world; St 22 and St772 in India [17], St 80 in Europe and Middle East [18], St 59 in Taiwan [19] and St 72 in Korea [20].

In the United States, the USA 300 lineage is the most well-studied clonal group. It is associated with the production of high levels of cytotoxins such as α-toxin, arginine catabolic mobile element type 1 and a set of virulence genes including lukS-PV/lukF-PV, sek, and seq [16,21]. And thus, it is incriminated in most of the community-associated MRSA infections causing severe skin and soft-tissue infections [16]. USA300 has been classified as one of the highest pathogenic strains [22], as it became an increasingly common cause of health-care-associated MRSA infections as well [23]. Interestingly, a variant of the USA300 called USA300 LA is predominant in some countries in Latin America such as Columbia and Ecuador [24].

Community-Associated MRSA (CA-MRSA) strains are genetically distinct from HA-MRSA strains [25]. CA-MRSA is mainly associated with skin and soft-tissue infections [26]. For instance, Carrel et al. (2015) reported in their review that among isolates with any reported anatomic site of isolation, skin, and soft-tissue infections accounted for 62.6% of USA300 and 19.1% of USA100 isolates. In addition, these, PVL-positive CA-MRSA causes severe diseases such as necrotizing pneumonia, and bacteremia [23].

CA-MRSA possesses SCCmec type IV, producing the virulence factor Panton-Valentine leukocidin (PVL), but frequently exhibit a non-multi drug resistance profile [13,27,28].

Certainly, fomites play a role in the transmission of CA-MRSA infections where inanimate objects are considered the potential reservoir and the source of these infections [29]. Pathogens may be transferred directly through the surface to mouth contact, or indirectly by contaminating hands/fingers, which subsequently transfer the pathogen to mouth, eye, ear, nasal cavities, or genitals [30–33]. Body fluids from infected areas may serve as a source of the transmission of the pathogen to fomites again [15,34–36]. Several studies have shown that MRSA survives on fomites for several hours, days or even months depending on the number of cells deposited and on other conditions related to the microstructure of fomites surfaces and environmental conditions [37–39].

This review will focus on the different types of community and hospital fomites known to harbor MRSA and their role in the widespread transmission of the CA-MRSA lineages and HA-MRSA nosocomial infections. The mode of transmission of MRSA from fomites to humans, and the methods to control MRSA colonization and transmission as well as the risk factors will be also addressed.

Community-associated methicillin-resistant *Staphylococcus aureus*

Community-associated MRSA (CA-MRSA) is defined as MRSA strains isolated from individuals who have not been recently exposed to the health care from patients exhibiting MRSA infections or having an infection incubation period at the time of admission to a healthcare facility [40]. Two decades ago, MRSA infections were confined only to healthcare systems, and were dubbed Hospital associated-MRSA, until the emergence of CA-MRSA in 1990s [41]. Interestingly, CA-MRSA is not limited to causing infections in community settings, but rather, they have been found to cause infections in hospitals and other healthcare settings [42]. CA-MRSA is now considered a public health problem in some parts of the world due to the increase in the number of infections caused by this pathogen [29]. Unlike HA-MRSA, which is associated with major and life-threatening infections, CA-MRSA usually causes minor skin and soft-tissue infections [26,43]. Nevertheless, CA-MRSA infections were reported to cause severe life-threatening illnesses such as pneumonia, pelvic osteomyelitis, septic thrombophlebitis, ocular infections, and necrotizing fasciitis [44]. The following parts of this review will shed light on the prevalence of MRSA in different community settings with special emphasis on the risk factors associated with these settings.

Athletic communities

The prevalence of MRSA infections among athletes in different types of sports and fitness centers is reviewed.

MRSA plays a major role in causing skin infections among athletes due to multiple risk factors associated with sport communities and athletes [45]. Several risk factors, such as physical contact between athletes, poor hygiene following physical activity and contaminated surfaces of fitness centers and training facilities, have greatly contributed to this problem [46]. In addition, multi-user equipment, high-contact surfaces, skin-to-skin contact, carpeted areas, locker rooms, and training areas are also among the major risk factors [46]. Furthermore, some risk factors are associated with certain types of sports. In football for example, skin abrasions, turf burns, and player tactical positions all contribute to the risk of obtaining an MRSA infection [47]. Indeed, numerous reports documented such infections in the last two decades [47–53]. Several other outbreaks of *Staphylococcus* infections in athletes and athletic settings were recently reported as outlined in the Table 1.

Emergency medical services and ambulances

Emergency medical services (EMS) settings and its personnel have also been colonized with a battery of microorganisms including MRSA. EMS personnel are at high risk of acquiring pathogens in the community and transmitting them to patients during medical emergencies [64–66]. In EMS settings, patients and EMS personnel occupy the same small area within the cabin of ambulances, and therefore, increasing the risk of MRSA transmission between patient, EMS personnel, and ambulance interior environment. In addition, some EMS systems suffer from a high rate of patient turnover, which means that subsequent patients will occupy the same cabin within a short period of time, and therefore, leaving a limited time for cleaning of the ambulance's interiors and equipment before reporting to duty. Such practice will certainly increase the risk of MRSA transmission. Several studies reported the colonization of MRSA in samples collected from ambulance's cabin interiors and equipment. In a study conducted on ambulances in the Chicago metropolitan area, 5 out of 71 ambulances tested in early 2010 were found contaminated with MRSA [67]. Similarly, MRSA was isolated from 2 out of the 17 ambulances investigated in July 2012 in a Spanish study conducted in Bilbao city [68]. In contrast, Roline et al. (2007) and Brown et al. (2010) documented the presence of MRSA in almost 50% of ambulances investigated in the West Coast and Southern Maine, respectively [69,70]. A recent study from Egypt reported that 46.1% of the *S. aureus* strains isolated in early 2016 from 25 ambulance cabins were MRSA [71]. In all these studies, MRSA was detected in both the patient-contact sites and the non-contacted sites inside the ambulance cabin.

Other similar studies reported lower percentages of MRSA contamination, for example, one study from Germany conducted in 2009 detected MRSA contamination only on a patient stretcher in 8 out of the 89 ambulances after the transport of MRSA-colonized /infected patients [72]. Likewise in California, USA, Kei, and Richards (2011) tested 40 samples collected in the summer of 2006 from many surfaces and devices inside the emergency department for the presence of *S. aureus* and reported only one sample (2.5%) to be positive for MRSA [73].

Fire stations

The communal lifestyle inside fire stations and the potential contact with high-risk populations puts firefighters at a high risk of exposure to pathogens. A study conducted in 2010 on environmental surfaces

Table 1. Summary of the recently published reports on MRSA prevalence inside athletic training facilities and fitness centers.

Country of report	Sample number	*S.aureus* isolated	MRSA percentage	Reference/Year
Ohio, USA	81 environmental samples from 9 High school training facilities and wrestling mats	ND	61.7%	[54]/(2010)
Ohio, USA	90 surface samples from 10 high school training facilities and related locker rooms	MD	42%	[55]/(2010)
Florida, USA	240 samples from university recreational facility, a high school gymnasium, and a private gymnasium	None	None	[56]/(2011)
Texas, USA	125 from various areas and equipment from athletic facility	38%	6%	[54]/(2012)
Virginia, USA	99 environmental samples from fitness center	10 samples	None	[57]/(2012)
Thohoyandou, South Africa	500 from hand touched surfaces inside 3 fitness center	36%	1.6%	[58]/(2046)
Tennessee, USA	32 from skin-contact surfaces inside 4 membership-based fitness centers	90.6%	37.5%	[59]/(2016)
Ohio, USA 16 fitness centers	288 swabs on fomites	38.2% of which 36.4% MDR	30%	[60]/(2019)
Malaysia, various fitness centers	42 swabs on fomites	73.81%	ND	[61]/(2018)
USA	Multiple samples on surfaces	ND	24% of surfaces were MRSA and VRE +ve	[62]/2020)
Ohio, USA	288 environmental swabs from 16 fitness facilities	38.2%	11.5%	[60]/2019
Ohio, USA	280 environmental samples from 10 playgrounds	31.8%	3.9%	[63]/2019

in fire stations and training sites in Arizona, USA revealed that the highest prevalence of MRSA was on couches (20%; 4/20); class desks (10%, 1/10); and commonly touched surfaces in offices (6.7% 2/30) [64]. In another study conducted in 2011, MRSA was isolated from 8% of the 653 samples swabbed from 33 different fire stations in Washington State, USA. Among the tested fire stations, 19 of 33 (58%) were positive for MRSA [74]. Likewise, another research group isolated MRSA from 44 of the 1,064 samples (4.1%) collected in 2011 from two fire stations in two independent districts in the northwestern United States [75]. In the last two studies, most of MRSA isolates were recovered from surfaces in the living rooms and garbage disposal areas.

Public restrooms

Restrooms or washrooms are considered shared public spaces with clear pathogen transmission potential [76]. Factors that are likely to contribute to the spread and persistence of pathogens inside restrooms include the presence of human feces, temperature, humidity, and the inappropriate use of disinfectants [77]. Several studies documented the isolation of MRSA from restroom floors, handles, toilet seats, doorknobs, and water faucets. Roberts et al. (2011) reported the isolation of MRSA from university dormitory bathroom floors, toilet flush handles, light switches, and doorknobs [78]. In a study conducted during the Muslim pilgrimage (Hajj) season in Saudi Arabia, swabs were collected from doorknob surfaces of 224 toilets serving hundreds of thousands of people. Out of the 42 *S. aureus* strains recovered, four (10%) were identified as MRSA [79]. In another study, 32 staphylococcal strains were isolated from 18 public washrooms in London, UK [77]. Three of these strains were identified as EMRSA-15 clone. In UK, the MRSA-15 clone is frequently isolated from patients with bacteremia caused by MRSA, which indicates that infection control measures failed to limit the spread of such clones in both hospital and community environments.

MRSA was also isolated from hospitals restrooms, especially the ones that might be shared between patients, staff, and visitors. In a study conducted in 2009 in a children's cancer hospital in Tennessee USA, daily samples were collected for 4 weeks from toilet seats in restrooms equipped with alcohol wipes and from restrooms lacking the alcohol wipes [80]. MRSA was isolated from 3.3% of samples collected from toilets lacking the alcohol wipes while no MRSA was isolated from the toilets equipped with wipes, indicating the significance of such simple measures in controlling the spread of this pathogen. A similar study conducted early 2012 in Japan investigated the presence of bacteria in bidet-type toilets at a university-affiliated hospital [81]. Of the 292 bidet-toilet seats sampled, MRSA was only found in one water-jet nozzle and one toilet seat. The results of these studies indicate that hospital toilets are potential risk to patients who may acquire MRSA from colonized persons. In addition, they represent a potential reservoir for nosocomial spread and serve as foci for community-acquired, hospital-related strains.

Public beaches

Beaches are considered a potential source of community-associated *S. aureus* infection, which is evident by the correlation between gastrointestinal illness, the ear, skin, and eye infections among bathers, and the density of *S. aureus* and other *Staphylococcus* species [82]. Bathers can shed *S. aureus* into water and sand, and *S. aureus* concentrations are correlated with the density of bathers and are attributed to human activities such as eating, playing, and littering [83], as well as other sources including stormwater [84], wastewater [85], sea mammals and domestic pets [86]. Several studies documented the isolation of MRSA from beach water, wet sand, and dry sand (Table 2) [82,87–96]. The results from all these studies indicate that beaches are potential reservoir for transmission of MRSA to bathers, especially those with skin lesions.

Homeless shelters

Closed community settings are considered areas of high-risk for CA-MRSA transmission, colonization, and infection due to increased person-to-person contact [97]. Homeless shelters are a very good example of such high-risk community settings. Crowdedness, lack of hygiene, and the frequent use of the facilities makes homeless shelters potential reservoirs for MRSA as well as a source of other pathogenic microorganisms [46]. In agreement with this, a study conducted between July 2012–June 2014 on a homeless shelter in Kansas City showed that individuals in

this homeless shelter are at high risk of obtaining an MRSA infection. In addition, the risk of infections within such individuals was significantly higher than the general population with a prevalence of 9.8% in homeless groups compared to 1.8% in the general population [97]. Another study conducted in April, 2006 in Canada revealed a 4.5% prevalence of MRSA colonization among residents of three homeless shelters in Ottawa, Ontario [98]. Poor hygiene, lack of sanitation, and immune compromise due to HIV and malnutrition are the most important risk factors contributing to the spread of MRSA infections among residents of such facilities [99].

Further, two studies conducted in USA by Landers et al. (2009) and Leibler et al. (2017) investigated the prevalence of *S. aureus* and MRSA nasal colonization in non-hospitalized homeless individuals in 2009 and

Table 2. Summary of different reported studies on the presence of MRSA in beach sand in several beaches in USA and South Africa.

Sample source	Note	Reference, Time of sample collection
Dry, wet and inundated sand from subtropical beach in Florida, USA	5 MRSA CFU per g of dry sand	[87](08/2009)
Sand samples were collected from 37 Californian beaches	One beach sample tested positive for MRSA	[92] (10/2009)
Sand from 2 beaches; Avalon and Doheny in California, USA.	MRSA was detected in 11 out of 155 sand samples collected over two years	[83] (08/2007)
Public intertidal beach sand and marine water from Washington State, USA	5 MRSA were isolated	[90] (02–09/2008)
Sand from 4 beaches (Avalon, Doheny, and Malibu Surf rider) in California, USA.	MRSA was detected in 10 samples (2.7%), out of 366.	[82] (05–09/2009)
Dry and wet sand from marine water beaches and freshwater beach in the Seattle WA area, USA	MRSA was isolated from one dry sand sample [1.9%; n = 53] and six from wet sand [14%; n = 43]	[91] (06–08/2010)
Sand from Marine Mammal Conservancy beaches, three recreational beaches, a residential beach in Florida, USA	MRSA detected in 7 sand samples out of 11 isolates from environmental samples	[93] (06–08/2011)
Sand samples from subtropical recreational beach from South Florida, USA.	3 out of 36 (8.3%) sand samples were positive for MRSA	[94] (07–08/2009)
Recreational marine sand and fresh water beaches from Seattle, USA.	Thirty-one (10.5%) of the 296 recreational beach samples were positive for MRSA	[88, 2010]
Intertidal beach sand in the Eastern Cape Province of South Africa	One out of 67 samples was positive for MRSA	[95] (04/2015-04/2016)
Water and sand from 10 freshwater recreational beaches in Northeast Ohio, USA	MRSA was detected in 15 (7.1%), of 210 samples	[96] (06–11/2014)

2015, respectively, and reported a range from 8.3% to 26.5%. This high prevalence of MRSA infections was attributed to medical risk factors including recent use of antibiotics, renal failure, endocarditis, and to behavioral factors, like alcoholism, smoking, and probably narcotics use [100,101].

Daycare centers

As discussed earlier, the prevalence of CA-MRSA is diverse, and multiple risk factors could contribute to the spread of infections. Children at daycare centers can also be reservoirs for MRSA and can further increase the spread of these pathogens in the community.

Several studies showed that children at daycare centers are at a low risk of obtaining MRSA infections. Nonetheless, restricted health care and hygiene strategies should be implemented to prevent the spread of MRSA infections among children and their families. Probably the shared use of toys and other objects by children might be the reason behind the incidence of MRSA among this group.

When surfaces in daycare centers were sampled, MRSA was isolated. In a study conducted between Feb 2009 and Feb 2010 on a child care center in Iowa, MRSA was isolated from only 3 out of the 214 surface samples collected [102]. In another study conducted by Ryan et al. (2013) in two daycare centers serving staff of two academic institutions in Florida, no MRSA was isolated out of the 87 surface swabs tested [103]. Indeed, the very low MRSA prevalence in these daycare centers reflect the implementation of high hygienic standards.

Prisons

Infections and outbreaks of CA-MRSA occur in correctional facilities, such as jails and prisons, due to poor hygienic practices, crowdedness, low educational status of prison inmates and the low hygienic quality of these facilities [104,105].

In a study conducted by Felkner et al. (2009) in Texas, USA, 132 swabs were collected from jail surfaces, from which 8 (6%) MRSA isolates were recovered [106].

A study conducted in 2004 aimed to examine the incidence of MRSA infections in a Texas prison population, and to identify the risk factors associated with these infections, showed an incidence rate of 12 MRSA infections per 1000 person out of a total of 299,179 inmates (both males and females) between 1999 and 2001 [107]. This study correlated elevated rates of MRSA infections between inmates and risk factors including the health of the inmates, circulatory diseases, cardiovascular diseases, diabetes, end-stage liver disease, end-stage renal disease, human immunodeficiency virus infection, or acquired immunodeficiency syndrome, and skin diseases [107]. Furthermore, the heavy usage of prison fomites and surfaces accompanied by low hygienic practices among prisoners certainly predisposes the users to infections including MRSA.

Unfortunately, the spread of MRSA infections through correctional facilities is difficult to control, nonetheless understanding the risk factors may help in the prevention of MRSA infections and to control its transmission, before a chronic problem that disseminates MRSA clones to the outside community happens [107].

Hotels

Hotel rooms and amenities are potential sources of community-associated infections due to the high number of guests passing through such settings, with the consequence of acquiring or transmitting of infectious agents [108]. In addition to that, hotels cleaning protocols are based on visual rather than microbial assessments [109]. Foodborne and waterborne infections and outbreaks in hotels have been documented by numerous reports. However, very few studies investigated the contamination of contact surfaces for the presence of infectious agents within hotel rooms and amenities [110]. Although no MRSA was isolated in their study, Xu and colleagues (2015) isolated multidrug-resistant *Staphylococcus* species from samples collected from inanimate objects inside rooms of three large hotels in London, UK. The authors of this study concluded that these *Staphylococcus* species represent potential reservoirs for MRSA [111]. In contrast, a study done in Canada in summer 2012 reported the presence of MRSA on high-contact surfaces inside 54 hotel rooms from 6 different hotel chains [108]. MRSA was isolated from the comforter, TV remote, bedside lamp, telephone, bathroom countertop, faucet, and toilet seat.

Academic institutions

School and university environments contain many high-contact surfaces frequently touched by thousands of students and staff on a daily basis. In such environments, close physical contact, common shared spaces, and variable hygiene habits among students are some factors likely to contribute to the transmission of infectious agents. MRSA have been isolated from a wide range of high-touch surfaces within schools and university environments, such as classrooms [112,113], restrooms [78,88,112,113], lockers [78,88], elevators [78,88], athletic training facilities [114,115], dormitory fomites [78,88,116] as well as public computers [117,118]. In addition, student's personal items have been found contaminated with MRSA including cellphones [119] and door keys [120]. Details of the MRSA prevalence in these places can be reviewed in the cited references.

Nursing homes

Elderly individuals in nursing care facilities are at an increased risk of acquiring MRSA due to their premorbid conditions, frequent hospitalization, shared rooms, and common areas [111,121]. Several studies reported the colonization of MRSA in nursing care facilities and residents as well [111,121–128]. MRSA have been also isolated from inanimate objects inside nursing facilities. For example, in Oct/Nov 2006, MRSA was isolated from 2 (1.2%) of the 163 environmental specimens collected from fomites in private and common rooms inside an elderly long-term facility located in USA [127]. These MRSA strains also colonized the residents in the contaminated rooms. In another study conducted in 36 residential elderly care homes in Hong Kong in the year 2010, more than 400 environmental samples were collected [121]. MRSA was isolated from bedside tabletops (19.4%), hand covers (15.6%), commodes (11.4%), sofas (8.6%), armchair handrails (8.3%), soap dispensers (5.7%) and wheelchairs (5.6%). In the same study, 20.4% of nasal swabs collected from 2776 residents tested positive for MRSA, which explains the presence of the MRSA on fomites and other surfaces in the facility.

Mobile phones and pagers

Mobile phones are increasingly becoming an inherent part of human's life. A major problem of using such devices is that they are rarely cleaned by the majority of their users, and thus, collect many types of bacteria and could act as reservoirs for the transmission of many pathogens [129–130]. Interestingly, Morris et al. (2012) conducted a one-day microbiological survey of hospital doctors fingerprints before and after using their mobile phones [131]. Among the 20 doctors enrolled in the study, the fingers of five doctors were contaminated with *Staphylococcus* species including MRSA. This indicates that doctors themselves can spread MRSA to patients.

Many researchers in different countries conducted studies on the prevalence of MRSA on mobile phones and pagers used by many health-care personnel and reported varying degrees of microbial contamination including MRSA. Table 3 lists a number of such studies. These studies indeed indicate the potential danger that mobile phones pose on the health of hospitalized patients and certainly shed light on the possible reasons behind the widespread of nosocomial infections inside hospitals. These studies also signify the difficulties encountered by hospital infection control personnel to eradicate nosocomial infections as mobile phones have become so indispensable, subjected to no rules for their use, and used freely within the health-care facilities.

MRSA prevalence in paper currency and coins

Paper currency and coins are frequently handled by many people with varying health and hygienic standards. Therefore, paper currency and coins can pose a public health risk especially when they are handled by individuals with direct contact with food, such as in restaurants and bakeries. MRSA can survive for a long time on paper currency and coins surfaces, making these surfaces potential reservoirs of infection [132].

In a study conducted by Gedik and coworkers (2013), the survival of MRSA and other bacteria on selected paper currencies from different countries was tested. Interestingly, it appeared that the types of fabric used to make paper currencies play a major role in supporting the survival of bacteria. For instance, some paper currencies like the Romanian Leo, US, and Canadian dollars supported confluent growth while some currencies like Indian Rupees, Euros, Morocco Dirhams, and Croatian Kunas did not support any bacterial growth or survival. In addition, some types of the currency fabric promoted the transmission of bacteria to handlers while other fabric types did not promote any transmission. The Romanian Leo was the most effective in transmitting *S. aureus* from the currency to volunteers followed by US dollar, while the Euro did not lead to any transmission [133]. Similarly, Tolba et al. (2007) tested the survival of several MRSA strains on metal coins and reported that no epidemic nosocomial or community-associated MRSA survived on coins lightly heat treated. It was concluded from this study that when no organic protection is offered, no MRSA will survive; however, bacteria may survive well when soil, pus, and blood is present on metal coins, therefore offering protection from drying and other environmental conditions [144]. In the same token, several researchers [39,145] reported that many Gram-positive and Gram-negative bacteria (see references for list of bacteria) can survive for months on surfaces that contain some organic matter, which might serve as a shield that helps in their survival. In a study from Nigeria conducted in Feb/Mar 2012, 128 paper currencies were collected from meat sellers and 36 (28%) of the tested bank notes were found contaminated with MRSA, while none of the very new currency notes contained MRSA [146]. In a similar study conducted by the same researcher (Neel, 2013), of the 205 different currency notes collected from a market place (hotels and restaurants), 53 (26%) and 6 (3%) were found contaminated with *S. aureus* and MRSA, respectively [147]. However, a meta-study conducted by Angelakis et al. (2014) reported the presence of multiple types of bacteria (MRSA was not specified) on paper currency and coins issued by many countries [132].

Table 3. Summary of the prevalence of pathogens on mobile phones.

Phone belongs to	No. of phones contaminated with bacteria (%)	No. of phones contaminated with MRSA (%)	Facility	Country of study	Reference
Hospital doctors and staff (132), college faculty and staff (54), medical students (100) and control group (100)	316/386 (81.8%)	16 (4%)	Hospital	India	[130]
Nurses, 32 (17.5%) from laboratory workers, and 57 (31.1%) from health care staff	179/183 (97.8%)	17 (9.5%)	Hospital	Turkey	[129]
HCWs[1]	157/213 (73.7 %)	1.4%	Intensive care units (ICUs), pediatric intensive care units (PICUs), and neonatal care units (NCUs)	Kuwait	[134]
Health care personnel	65/120 (54.2%)	11(16.4%)	General	India	[135]
Hands and mobile phones of HCWs		16/27 (59%)	General	India	[136]
Mobile phones of HCWs	13/101 (13%)	4/101 (4%)	General	Korea	[137]
Mobile phones with HCWs	144/200 (72%)	26/200 (13%)	General	India	[138]
Pagers of HCWs	12/100 (12%)	3 (3%)	General	USA	[139]
Students	107/309 (34.6%)	ND[2]	University	Japan	[140]
Patients, patients' companions, visitors, HCW	121/133 (90%) 58/67 (85.6%)	ND	Hospital	Turkey	[141]
Patients & HCW	40/40 (100%)	21 (53%)	Hospital	Egypt	[142]
Veterinary students, technicians, residents/interns and clinical faculty	3/123 (1%)	1/123 (0.8%)	Veterinary teaching hospitals	Canada	[143]

[1]HCW; health-care workers
[2]ND: not determined

ATMs

Automatic teller machine (ATM) surfaces are likely to be contaminated with bacteria due to their direct contact with hands from multiple users. People with different socioeconomic backgrounds and hygienic statuses use ATMs on a daily basis. The point of contact is the user's fingers touching the keypad and/or screen surfaces. Several studies reported the isolation of low levels of MRSA from ATM surfaces [78,148–150]. Other studies reported a high prevalence of colonization of ATMs with coagulase-negative *S. aureus* [151,152].

MRSA and public transportation

Millions of people use public ground transportation on a daily basis. Thus, ground transportation serves as one of the favorable routes of microbial transmission. Users touch and contaminate objects within transportation vehicles such as door handles, seats, windows and they may even drop contaminated items on the floor such as tissue. This certainly creates a potential reservoir for multiple types of microbes, some of which might be very pathogenic, while others might be opportunistic or nonpathogenic [153]. Table 4 summarizes the prevalence of MRSA in public transportation vehicles and waiting stations reported by several studies.

Hospital associated MRSA and fomites

Nosocomial or healthcare-associated infections (HAI) are infections acquired while receiving medical care at a health facility but were not present at the time of admission. In the year 2011, The World Health Organization reported that on average 7–15% of the population in developed and underdeveloped countries, respectively, suffer from HAI at any given time with a mortality rate at nearly 10% [165].

These infections have severe consequences on the life status of patients and are considered a high financial burden for health-care systems [166–169]. The discussion of HAI is often associated with MRSA as a major causative agent for the problem [170–172]. MRSA is one of the most prevalent pathogens among HAIs and it has a severe impact on health, especially among immunocompromised patients such as neonates and ICU patients [173–176]. Inside hospitals, MRSA can be transmitted by air, droplets, and through direct (skin-to-skin contact) or indirect contact (via fomites) [177,178]. Any inanimate object at a health facility is a potential fomite, even healthcare personnel themselves could be a transmission source through their contaminated apparel [179–182].

MRSA survival on different hospital surfaces

A critical factor that allows the transmission of MRSA from a person to the environment and then to other people, is the pathogen's ability to survive on different types of surfaces under low humidity conditions, and its persistence on these surfaces for extended periods [39,183]. It is noteworthy that the antibiotic-resistance trait of MRSA does not affect the length of the survival period on fomites compared to, for example, Methicillin-sensitive *S. aureus* (MSSA). Rather, MRSA survival time on fomites is affected by inoculum concentration [184]. This is consistent with the phenomenon of cryptic growth; where cells in a nutrient-limited environment will live on the remains of surrounding dying cells, and thus, an increased inoculum concentration will provide more dying cells for longer periods of time to sustain the lives of the remaining bacteria [185]. However, others reported contradictory data on the differences in the survival ability/length of MRSA vs MSSA. For instance, Wagenvoort and Penders (1997) reported the survival of an MRSA linage for 175 days in hospital dust while an MSSA linage survived only for 4 weeks under the same conditions [186]. Zarpellon et al. (2015) reported the survival of MRSA and vancomycin-resistant *S. aureus* (VRSA) on vinyl floors and formica for 40–45 days while on latex for only 2 days while MSSA survived on latex for only one day (Table 5) [187].

In a study aimed at determining the survival time of different types of bacteria on common hospital materials, MRSA was shown to persist on polyester for the longest time, reaching up to 56 days. However, on cotton, the bacterial survival was far less than that on polyester. For instance, MRSA lasts for one week on pure cotton and two weeks on cotton terry, while it lasts on polyester-cotton blend for less than one week [184]. These observations have significant infection control implications. For example, polyester is commonly used in making privacy drapes that are frequently touched by patients and staff. The frequent use of the polyester drapes, alongside the increased survival time of MRSA on them, makes them a high-risk source for hosting and transmitting MRSA. Even though MRSA survives for the least period on polyester-cotton blends, it does survive for at least a day. Polyester-cotton blends are most commonly used in making different kinds of clothes including healthcare workers' (HCWs) lab coats and scrubs. Thus, even within one day, the movement of the HCWs between different patients could promote transmission of MRSA from one patient to another [184]. Apparently, the length of MRSA survival period on surfaces and textiles differs with the type of surface or textile it occupies as well as its initial inoculum size and other environmental conditions local to each tested place.

MRSA transmission to- and from- inanimate objects

Fomites or inanimate objects, when contaminated with microbes, can serve as reservoirs for the

Table 4. Summary of the published studies on the presence of MRSA inside transportation vehicles and stations.

Type of swab- sample collected	Type of transportation vehicle/station (number)	No. (%) of samples/vehicles positive for MRSA out of the total collected	Country of study	References, Time of sample collection
Handrails (1400 swabs)	Trolleybuses, trams and buses (n = 55)	0% of samples	Belgrade, Serbia	[154] (NI) *
Handrails	Buses (n = 85)	26% of buses	Oporto, Portugal	[155] (05–2009/02-2010)
Straps and handrails	Subway trains (n = 349)	2.3% of trains	Tokyo and Niigata, Japan	[156] (2008–2010)
Handrails, ticket machines and hand-touched surfaces	buses and stations	0%	Lyon, France	[157] (NI)
Handrails, seat rails, handgrips, stop buttons and tickets machine	Buses (n = 199)	36.2% of buses	Lisbon, Portugal	[158] (05–2011/05-2012)
Pooled samples from handrails, seats, seat rails, driver's area	Buses (n = 40)	63 % of buses	Ohio, USA	[159] (07–2010/10-2010)
handrails and stop buttons	Buses (n = 112)	16.1% of buses	Porto, Portugal	[160] (10–2010/05-2011)
Hand rails, seats, stanchions, Ticket Vending Machines (TVMs) and escalators.	stations and carriages	2.5% of stations	Guangzhou, China	[161] (11–2013)
Toilet door handles	Airport (n = 136)	0.7% of airports	Worldwide	[162] (12–2012/11-2015)
Grab rail, armrest and vinyl seat	Buses (n = 15)	12 isolates from 45 samples	Chittagong City, Bangladesh	[163] (NI)
380 surface samples	railway stations and coach stations	1.58% of the 149 *Staphylococcus* species	China	[164] (12–2013-01-2014)
Handle and seat surfaces	Public transportation vehicles (n = 28)	31.4 % of vehicles	Kathmandu valley, Nepal	[153] (06–2017-08-2017)

* NI; not identified

Table 5. MRSA survival rate on different hospital surfaces.

Reference	Type of fomite	Survival (days)
Fabrics		
[184]	Smooth cotton	4 to 21
	Cotton terry	2 to 14
	Cotton-polyester blend	1 to 3
	Polyester	1 to 40
[188]	Cotton	37
	Cotton-polyester blend	37
	Wool	41
	Silk	37
[183]	Polyester cloth curtain	9
Plastics		
[183]	Plastic charts	11
	Plastic laminated bedside table	> 12
[184]	Polypropylene plastic	40 to > 51
Other surfaces		
[189]	Glass	41
	Tile	45
	Countertop	≥ 60
[190]	Dry mops	56
[187]	Vinyl floors and formica	40
	Latex	2

dissemination of disease-causing agents to human hosts. Each of these inanimate objects can host an entire community of bacteria, viruses, fungi, or even metabolic products such as toxins that can lead to illnesses in humans [191]. The transmission of CA-MRSA from fomites to humans certainly plays an important role in the spread of MRSA in communities as well as in hospitals.

Patients colonized or infected with MRSA are considered the main contributors to MRSA contamination of their surrounding environment. Sexton and his colleagues (2006) have demonstrated that in hospital rooms where MRSA patients are isolated, more than half of the cultured surfaces tested positive for the pathogen, and the isolated strains were similar to those found in samples from patients occupying the same rooms as determined by pulsed-field gel electrophoresis (PFGE) analysis [192]. The frequency of contamination is influenced by the number and type of culture-positive body sites; patients with an MRSA-contaminated active wound, in the urine, or having diarrhea, shed more of the pathogen than patients who are only colonized, or just harbor the pathogen in other body sites [193,194]. Furthermore, another study has shown that in rooms occupied with patients who have MRSA colonizing their groin, 31% (75/240) of the surfaces were contaminated, compared to only 3.6% (27/760) contaminated surfaces in rooms occupied with MRSA-positive patients whose groins are MRSA-free [195]. Not surprisingly, it is more likely to find contaminated surfaces in the patient's surrounding environment if MRSA is isolated from the palm of the patient [196]. Nonetheless, MRSA could be found in the vicinity of the immediate environment of MRSA-negative patients, which could be transmitted via visitors or HCWs. Villamaria et al. (2015) collected samples from surfaces of 100 hospital rooms and were able to isolate 202 and 1,830 MRSA isolates from 32 MRSA-

Table 6. MRSA contamination rate on different fomites in patient's surroundings.

Reference	Source (room)	Type of fomite	MRSA Contamination rate (number of contaminated fomites/total sample)
Tables			
[216]	MRSA-positive patients[a]	Over bed table	25% (6/24)
[196]	MRSA-positive patients	Over bed table	22.4 (19/85)
[194]	Gastrointestinal MRSA-positive patients with diarrhea	Table	62.5% (5/8)
	MRSA-negative patients[b]	Table	16.7% (1/6)
[193]	Wound or urine MRSA-positive patients	Over bed table	44.4% (12/27)
[217]	MRSA-positive patients	Over bed table	3.8% (1/26)
	MRSA-negative patients	Over bed table	0% (0/9)
[203]	ICU	Bedside table	40% (4/10)
[218]	Burn unit	Bedside table	6.67% (2/30)
Beds			
[216]	MRSA-positive patients	Bedside rails	31.6% (6/19)
[196]	MRSA-positive patients	Bed linens	40.2% (41/102)
		Bed side rails	20.9 (18/86)
[194]	Gastrointestinal MRSA-positive patients with diarrhea	Bedside rails	100% (8/8)
	MRSA-negative patients	Bedside rail	66.7% (4/6)
[193]	Wound or urine MRSA-positive patients	Bed linen	55.6% (15/27)
		Bedside rails	29.6% (8/27)
[217]	MRSA-negative patients	End of bed	3.8% (1/26)
	MRSA-positive patients	End of bed	0% (0/10)
[203]	ICU	Bed rails	50% (10/20)
		Bed crank	40% (4/10)
[210]	Male surgical ward	Bed rails	4.7% (6/128)
[218,219]	Burn unit	Bed rails	6.67% (2/30)
Curtains			
[216]	MRSA-positive patient	Curtains	0% (0/24)
[217]	MRSA-positive patients	Privacy curtain	12.5% (1/8)
	MRSA-negative patients	Privacy curtain	0% (0/26)
Door handles			
[196]	MRSA-positive patient	Inner side room door handle	2.7% (2/74)
		Outer side room door handle	4.1% (3/74)
[194]	Rooms of gastrointestinal MRSA-positive patients with diarrhea	Room door handles	37.5% (3/8)
	MRSA-negative patients	Room door handles	16.7% (1/6)
[220]	MRSA-positive patients	Room door handle	19% (4/21)
	MRSA-negative patients	Room door handle	7.4% (13/175)
[193]	Wound or urine MRSA-positive patients	Bath door handle	22.2% (6/27)
		Room door handle	7.4 (2/27)
[210]	Male surgical ward	Room door handle	10.7% (3/28)
[73]	Urban Emergency department	Door handle of ambulance bay door key pad	2.5% (1/40)
Button devices			
[193]	Gastrointestinal MRSA-positive patients with diarrhea	TV remote	75% (6/8)
	MRSA-negative patients	TV remote	16.7% (1/6)
	Gastrointestinal MRSA-positive patients with diarrhea	Nurse call button	37.5% (3/8)
	MRSA-negative patients	Nurse call button	33.3% (2/6)
[221]	Colorectal surgical unit	Bed-control handsets	12.9% (9/70)
[222]	Randomly chosen hospital rooms	Bed handset	0.87% (1/115)
[210]	Male surgical ward	Nurse call button	7.7% (2/26)
Toilets			
[194]	Gastrointestinal MRSA-positive patients with diarrhea	Toilet seat	62.5% (5/8)
		Toilet rail	50% (4/8)
	MRSA-negative patients	Toilet seat	33.3% (2/6)
		Toilet rail	16.7% (1/6)
[218,219]	Burn unit	Toilet floor	10% (3/30)
Other furniture and floor			
[194]	Gastrointestinal MRSA-positive patients with diarrhea	Dresser	50% (4/8)
	MRSA-negative patients	Dresser	16.7% (1/6)
[193]	Wound or urine MRSA-positive patients	Floor	59.3% (16/27)
[217]	MRSA-negative patients	Bulletin board	0% (0/23)
		Chair back	16% (4/25)
		Television	0% (0/23)
	MRSA-positive patients	Bulletin board	0% (0/7)
		Chair back	0% (0/10)
		Television	0% (0/8)
[210]	Male surgical ward	Furniture	11.3% (12/106)
		Floor	8.6% (7/81)

(*Continued*)

Table 6. (Continued).

Reference	Source (room)	Type of fomite	MRSA Contamination rate (number of contaminated fomites/total sample)
[223]	ED in tertiary care hospital	Treatment room desk	1.4% (1/69)
Others			
[210]	Male surgical ward	Ventilation duct/grill	8.3% (4/48)
		Radiator	36.4% (16/44)
[224]	Hospital wards	Multiple environmental locations	24.7% (174/705)
[218]	Burn unit	Chairs and nurse station	6.67% (2/30)
[225]	Tertiary care hospital	Nurses coats	2% (9/436)

a MRSA-positive patients are patients infected or colonized with MRSA
b MRSA-negative patients are patients who are MRSA-free

noncontact rooms, and 68 MRSA-contact rooms, respectively. One can speculate that the presence of MRSA in rooms occupied by MRSA-free patients can be attributed to residual contamination from previous occupants, visitors, or HCWs with hands or gloves contaminated with MRSA. Gloved hand contamination is just as likely to occur after contacting commonly examined skin sites in MRSA patients, and after contacting the patient's surrounding environment [197]. In one experiment, Desai et al, (2011) assessed the survival and transmission of CA-MRSA strain USA 300–0114 from 9 different fomites that are used by humans [198]. Experimentally, CA-MRSA was transmissible from many fomites to skin with the non-porous fomites exhibiting transmissibility for many weeks, while porous fomites transmit pathogens fast but for short times. In another study, Moore et al. (2013) evaluated the MRSA transmission between different types of gloves worn by HCWs and fomite surfaces [199]. In this study, they have found that the bacteria transfer occurs at a very low rate ranging from 0% to 20%, with the difference is anticipated due to variations in the type and hydrophobicity of the materials used to make glove. Surface characteristics certainly influence microbial survival and the rates of transfer to and from humans, in addition to the type of use and the frequent use of gloves by the end users.

MRSA-contaminated hospital surfaces and instruments, and their role in MRSA outbreaks

Several studies have reported the presence of MRSA contamination on different fomites in the patient's surrounding environment, highlighting the potential role of these inanimate objects in transmitting the pathogen [200,201]. Using a quantitative approach based on the frequency of patient and HCWs contact with different objects, Huslage et al. (2012) defined 'high-touch surfaces' as the bed surface, bed rails, overbed tables, intravenous pumps, and supply carts [202]. In rooms occupied with patients having heavy gastrointestinal MRSA colonization, a study conducted in England between June 2005 and Feb 2006 showed that the pathogen had colonized bedside rails, blood pressure cuffs, television remote controls, and toilet seats (Tables 6 and Tables 7) [194]. In addition, one study conducted in Brazil in Oct 2008, reported MRSA colonization of 46% (29/63) of cultured surfaces close to ICU patients. These surfaces were bedside rails, bed cranks, bedside tables, infusion pump buttons, and cotton gowns [203]. Other instruments and accessories that are used frequently in the hospital were also tested and found to be contaminated with MRSA and other bacteria. For instance, X-ray facilities tested positive for MRSA as well as chairs in nursing stations and land phones and others.

A yearlong study (March 2009-Feb 2010) performed by Balen et al. (2016) in USA showed that the hospital's environmental surfaces that are exposed to general public contact could also be colonized by MRSA. In this study, hand-rails, coffee machines, and elevators were the most commonly contaminated general public surfaces, and to lesser extent, hand sanitizer dispensers and land phones were shown to be contaminated at certain times [204]. The results from the abovementioned study highlight the fact that different hospital surfaces are colonized with MRSA, but they do not provide a direct link for MRSA transmission from fomites to patients. Such links could be provided by outbreak reports, in which, the causative agent is attributed to contaminated inanimate objects. Molecular typing methods such as PFGE, Multi-locus sequence typing (MLST), variable number tandem repeats (VNTR), restriction fragment length polymorphism (RFLP) and whole-genome sequencing provide the means for linking pathogens isolated from different places and patients [205–207]. For example, in an MRSA outbreak in a postnatal ward in UK, which lasted for almost a year (Nov 89-Oct. 90) and affected 82 mothers and 28 babies, the bed mattresses were found contaminated with the same MRSA isolate that was identified as the causative agent for the outbreak. The mattresses were covered with old covers that were permeable to water. This outbreak was contained after the rooms were thoroughly cleaned, and the old furniture and mattresses were incinerated [208]. In another MRSA outbreak inside a plastic surgery/burn unit that occurred in 1996 in Manitoba, Canada,

Table 7. MRSA contamination rate in HCW contact objects.

Reference	Source	Fomite	Contamination rate
[226]	Teaching hospital, Italy	Telephone handsets	18.9% (7/37)
		Computer keyboards	22.2% (6/27)
[223]	ED in Tertiary care hospital Baltimore, USA	Nursing station keyboard,Nursing station phone	4.3% (3/69)
			1.4% (1/69)
[204]	Two wards in an academic medical center, USA (a year-long study)	Chart holders	45.8% (11/24) and 37.5% (9/24)
		Medicine carts (drawers)	20.8% (5/24) and 41.7% (10/24)
		Medicine cart laptops	12.5% (3/24) and 16.7% (4/24)
		Copy machine	16.7% (2/12) and 8.3% (1/12)
		Medicine room	50% (6/12)
		Computers	8.3% (3/36) and 25% (3/12)
		Access doors to office's halls of faculty and health care professionals	33.3% (4/12)
		Markers at main nurses' board	8.3% (1/12)
		General use laptops	14.3% (3/21) and 15% (3/20)
[180]	Radiology department, Korea	X-ray cassettes	16.2% (6/37)
[227]	X-ray facilities	MRI	0.8% (1/25)
[228]	Tertiary care center, Saudi Arabia	ICU patients' files	6.8% (7/102)
		Surgery ward patients' files	1.1% (1/89)
[229]	General hospital, Japan	Working tables in ward staff centers	30.4% (17/56)
[230]	Medical center, Taiwan	Keyboard	0.7% (2/282)
		Mouse	0.4% (1/282)
[215]	Tertiary hospital, Taiwan	Special units' medical charts	9.3% (10/107)
		General wards medical charts	(18/455)
Medical devices			
[194]	Gastrointestinal MRSA-positive patients with diarrhea	Blood pressure cuffs	87.5% (7/8)
	MRSA-negative patients	IV pump	25% (2/8)
		Blood pressure cuffs	16.7% (1/6)
		IV pump	0% (0/6)
[193]	Wound or urine MRSA-positive patients	Blood pressure cuff	33.3% (9/27)
		Infusion pump button	18.5% (5/27)
[231]	General intensive care unit	Blood pressure cuffs	5% (5/100)
[232]	Hospital wards	Blood pressure cuffs	8% (2/24)
[233]	Critical care unites	Blood pressure cuffs	66.6% (33/50)
[234]	Different places in a teaching hospital	Blood pressure cuffs	20% (10/50)
[235]	Used by medical house Staff	Tourniquets	29% (7/24)
[236]	Used by hospital staff public and private sector hospitals	Tourniquets	17.4% (9/51)
[203]	ICU	Infusion pump button	30% (3/10)
		Surgical gallons	46% (6/13)
[210]	Male surgical ward	Medical equipment	13.2% (16/121)

Table 8. Summary of the range of MRSA contamination rate on HCW attire and devices, (adapted from [179]).

Sample type	MRSA contamination rate	Number of studies
Stethoscopes	0–42%	20
Digital devices	0–50%	23
White coats	0–79%	5
Neckties	3–32%	3
Pens	0–25%	4
Uniforms	4–20 %	4
ID badges	0–5 %	2

a hand-held shower and a shower stretcher in the hydrotherapy room tested positive for the outbreak strain, and were implicated as the source of contamination [209]. Moreover, in an outbreak in a male surgical ward that lasted from Jan 98 tell May 99 and affected 69 patients in UK, the MRSA strain isolated from the ward environment was the same one isolated from all patients [210]. Further, MRSA-contaminated ultra-sonic nebulizers inside a university tertiary care hospital in the Netherlands, was identified as a potential source of an outbreak that lasted for almost 6 months (May–Nov 2000) and spread to two ICU units. Such outbreaks demonstrate the role of fomites in aerosol transmission of MRSA, a route of transmission that causes a wider spread of the pathogen and more challenging to be contained [211]. Table 6 lists all the different studies reporting MRSA in hospital environments and fomites.

In a very recent study, Phoon et al. (2018) tested environmental samples from a tertiary hospital in Malaysia and isolated only one MRSA clone that was a multi-drug resistant [212].

HCWs contribution to environmental MRSA contamination

Hospital regulations force HCWs who are in direct contact with MRSA-colonized patients to wear gloves and gowns. However, even with those enforced guidelines, studies have shown that after the removal of gloves and gowns, many HCWs acquire the pathogen on their hands [213,214]. Unfortunately, not all health-care personnel are adherent with hand hygiene guidelines, which is a necessity for the prevention of MRSA transmission between HCWs and patients. For example, in a study aimed at examining MRSA contamination on medical charts, 4% and 9.3% of the medical charts examined in general wards and special units, respectively, were contaminated. Such results could be explained by the lack of handwashing by HCWs between patient rounds [215]. Beside medical charts, various medical objects and devices that are in direct contact with HCWs have been shown to be contaminated with MRSA (Table 7). Moreover, several reports have demonstrated the presence of MRSA contamination on HCWs attire and personal devices. A recent systematic study has shown that white coats, neckties, pens, and stethoscopes as well as other digital devices are commonly contaminated with MRSA. The results of this study are summarized in Table 8 [179]. The results from these studies could be utilized to redefine practices and guidelines aimed at preventing and controlling MRSA infections inside healthcare settings.

MRSA infection control strategies

MRSA is one of the most important nosocomial infections in hospitals that also causes infections in the community. MRSA infections created so much burden on the health systems and led to thousands of deaths annually all over the world. Several countries have launched aggressive measures to curb this pathogen and decrease the incidences of MRSA outbreaks. Different measures were taken including the availability of bedside hand sanitizer, isolation of MRSA patients in single rooms, use of barrier precautions inwards containing MRSA patients, decolonization of MRSA patients using mupirocin, and routine antiseptic washing of MRSA patients with chlorohexidine [237]. These procedures were implemented in both surgical wards and ICU units but with more heavy use in ICU units. It appeared that countries with decreasing MRSA proportions showed a strict implementation of various prevention measures while those with lower decreasing proportions did not follow such strict measures.

The environment may have a minor role in propagating MRSA's spread overall, but this role is certainly important [238]. Decontaminating the hospital environment, therefore, is vital for controlling MRSA spread among patients and different hospital wards. All the instruments used by doctors and nurses, linen, curtains, floors, attires, beds, tables, and many other instruments are considered parts of the environment that should be decontaminated.

Are MRSA incidences increasing or decreasing?

There is a plethora of studies summarizing the dynamics of MRSA incidences over the years from all over the world. However, it is very hard to get a consensus on a trend of whether MRSA-related infections are increasing or decreasing globally.

This part summarizes data from studies reported from scattered parts of the world showing that MRSA infections are generally decreasing. For instance, from 2005 to 2010, MRSA bacteremia cases dropped in 10 European countries; however, these years also witnessed the appearance of the community-associated MRSA strains [239]. In contrast, Otter and French (2010) have stated that generally in Europe MRSA incidence rates are low compared to other regions, but actually are still increasing in some parts of Europe [240]. In a recent study, McGough et al. (2018) reported a decreasing rate of both *S. aureus* and MRSA in 28 European countries between 2000 and 2016 [241].

In Germany, the proportion of MRSA among *S. aureus* isolates decreased continuously from 16% in 2010 to 10% in 2015 and the decrease was seen for all types of care and for the majority of sample types [242]. Further, a decreasing trend from 64.7% to 36.4%, in prevalence of MRSA bloodstream infections was observed in Greece between the years 2000–2015 [243].

Contrasting results concerning community-associated MRSA infections were reported from Ontario, Canada. A significant increase in community-associated MRSA from 23.6% in 2010 to 43.0% was observed in 2016 [244]. In the same token, in another report from Canada, the proportion of CA-MRSA genotypes increased significantly from 20.8% in 2007 to 56.3% in 2016 while HA-MRSA genotypes decreased from 79.2% to 43.8% throughout the study period [245]. Kavanagh et al. (2017) conducted a thorough review of several studies to analyze the trend of the MRSA infections in the USA [246]. They have reported that the incidences of MRSA infections varied widely depending upon the type of population studied, the types of infections captured, and the definitions and terminology used to describe the results in these studies. Kavanagh et al. (2017) concluded that they were unable to identify a firm evidence that there is a significant decrease in the total number of HA-MRSA infections in the USA. In contrast, the Military veteran's health-care system in the USA reported a decrease of 87% MRSA infections in ICUs and about 80% reduction in other wards between Oct 2007 and Oct 2015. However, in a CDC report published in 2019 observing MRSA trend from 2005 to 2012, they have concluded that rates of hospital-onset MRSA bloodstream infection decreased by 17.1% annually, but the decline slowed during 2013–2016 [247]. Further, community-onset MRSA declined but less markedly with a 6.9% annual rate during 2005–2016 and relating the decline to a general decline in health care–associated infections [247].

In a study conducted in Shanghai, China to evaluate the trend of the MRSA cases over ten year period, Dai et al. (2018) reported that the proportion of MRSA markedly decreased from 83.5% to 54.2%, in the years between 2008 and 2017 [248]. Similarly, there was a 64.6% decrease in the number of isolates of methicillin-resistant *S. aureus*, in Taiwan and Korea over the study period which lasted from 2008 to 2015 [249].

However, it is very hard to obtain a consensus on whether the MRSA incidence is decreasing or increasing in the world. Nonetheless, the author's impression is that the infection control measures are helping in decreasing MRSA and other nosocomial infections in places where the control measures are strictly adhered. A similar effect was not observed in places where such control measures were not applied.

Emerging antibiotic-resistance infections other than MRSA

MRSA is not the only multidrug-resistant bacteria (MDR), there are other microbes that have developed multi-drug resistance to many antibiotics. Vancomycin-Resistant *Enterococcus* (VRE), Carbapenem-Resistant *Enterobacteriaceae* (CRE) and the Extended Spectrum Beta Lactamase (ESBL) producers *Enterobaceriaceae* are examples of MDR organisms that are causing major problems for the health systems worldwide. Nevertheless, it appears that MRSA is still leading the way globally in the high number of cases [237,250–252].

Conclusions

Fomites, whether in community or hospital settings, can be contaminated with multiple types of pathogenic bacteria. Among these, *S. aureus* are frequently isolated from all objects that are tested for contamination. Hospital fomites represent a major source of nosocomial infections, S. *aureus* for instance, was isolated from every tested object. Further, MRSA was isolated almost from all tested objects too, but to a lesser extent than MSSA. Interestingly, fomites in public community environments such as transportation, daycare, athletic facilities, airports, and other high-traffic areas were also considered reservoirs for many pathogenic bacteria including *S. aureus*, and particularly MRSA, which indicates the lack of proper hygiene practices among individuals who work or participate in activities associated with these environments. This certainly poses a risk of spreading the infectious diseases that are challenging to manage from public health perspectives.

Furthermore, some of the studies highlighted in this review described the differences among the various types of fabrics and fomites used in hospitals in supporting the growth of multiple pathogenic bacteria. The results from these studies should have an impact on the healthcare policy decision-makers when purchasing the textiles, clothing, and construction materials for hospital settings and personnel.

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