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REVIEW ARTICLE

Shoe soles as a potential vector for pathogen transmission: a systematic review

T. Rashid[1,2], H.M. VonVille[2], I. Hasan[3] and K.W. Garey[1,2]

1 University of Houston College of Pharmacy, Houston, TX, USA
2 The University of Texas Health Science Center at Houston School of Public Health, Houston, TX, USA
3 University of Edinburgh, Edinburgh, UK

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Correspondence
Kevin W. Garey, University of Houston College of Pharmacy, 1441 Moursund street, Houston, TX 77030, USA.
E-mail: kgarey@uh.edu

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Summary

Shoe soles are possible vectors for infectious diseases. Although studies have been performed to assess the prevalence of infectious pathogens on shoe soles and decontamination techniques, no systematic review has ever occurred. The aim of this study was to perform a systematic review of the literature to determine the prevalence of infectious agents on shoe bottoms and possible decontamination strategies. Three electronic bibliographic databases were searched using a predefined search strategy evaluating prevalence of infectious pathogens on shoe bottoms and decontamination strategies. Quality assessment was performed independently by two reviews with disagreements resolved by consensus. Thirteen studies were identified that supported the hypothesis that shoe soles are a vector for infectious pathogens. Methicillin-resistant *Staphylococcus aureus*, *Clostridium difficile* and multidrug-resistant Gram-negative species among other pathogens were documented on shoe bottoms in the health care setting, in the community and among food workers. Fifteen studies were identified that investigated decontamination strategies for shoe soles. A number of decontamination strategies have been studied of which none have been shown to be consistently successful at disinfecting shoe soles. In conclusion, a high prevalence of microbiological pathogens was identified from shoe soles studied in the health care, community and animal worker setting. An effective decontamination strategy for shoe soles was not identified. Studies are needed to assess the potential for contaminated shoes to contribute to the transmission of infectious pathogens.

Introduction

Environmental surfaces and fomites are important components in the transmission dynamics of healthcare-associated infections (Li *et al.* 2009). One such fomite are shoes worn by health care personnel, patients and visitors. Historic studies performed in the 1970s demonstrated that redistribution of bacteria into the air from the operating room floor accounted for up to 15% of all airborne bacteria (Hambraeus *et al.* 1978). Walking on contaminated floors was a more effective airborne dispersal method than either mopping or sweeping. More recently, our research group demonstrated that up to 40% of shoes in the community are contaminated with toxigenic *Clostridium difficile* (Alam *et al.* 2014). Despite the known possibility of shoes to be a possible vector for infectious diseases, very little research in this area has occurred. In addition, we were not able to identify any systemic review that focused on shoes as a fomite for infection transmission and strategies for shoe decontamination. This may be especially important for multidrug-resistant organisms in which systemic antibiotics may not be effective. Thus, the objective of this study was to systematically review the literature to assess (i) the evidence that shoe surfaces are vectors for infectious disease transmission and (ii) evaluate the evidences for the efficacy of disinfectants to decontaminate shoe surfaces.

Methods

Two separate systematic reviews were conducted using the preferred reporting items of PRISMA to address the two study objectives (Moher *et al.* 2009). To assess the evidence that shoe surfaces can be vectors for infectious disease transmission, the eligibility for inclusion required that studies examined the microbiological contamination of shoe surfaces including shoe bottoms. Studies were excluded if they (i) were not related to shoe soles or shoe surfaces as a mode of fomite transmission; (ii) were laboratory-based studies with induced contamination; (iii) looked at various bacterial, viral or fungal infection, diagnosis and treatment in human beings; (iv) were a genetic study or modelling study or a bench-work; (v) were not original research; (vi) were related to knowledge, perception and belief and (vii) looked at infection control practices or were outbreak investigation. Only relevant articles published in English from 1946 to December 14th 2015 with available full texts were included in the final review. We did not limit by date of publication, only by language. We systematically searched articles indexed in Medline (Ovid), PubMed (NLM) and Embase (Ovid) using a broad set of keywords and MeSH terms to maximize sensitivity; the date of the last search was December 14, 2015. Concepts that made up the search included fomites, environmental microbiology and transmission. Human apparels were included in the search to avoid missing articles with a shoe subcomponent. A complete search strategy for each database can be found in the supplementary materials (Table S1). Also, bibliographies of identified articles were searched as well as Scopus (Elsevier) for any additional studies not found through initial search of the databases. An auto alert service was setup in Medline (Ovid) for notification of any related articles matching the search term. A second systematic search was conducted using the same databases and date ranges to evaluate strategies to decontaminate shoe surfaces. Eligibility criteria for selected articles included studies that assessed the efficacy of disinfectants on shoe surfaces either in the hospital or at the community. Articles were excluded if studies (i) were not related to decontamination of shoe surfaces including shoe soles; (ii) investigated pathophysiology of infectious diseases including diagnosis and treatment; (iii) were related to decontamination of the interior of the shoes; (iv) were animal studies; (v) were not original research, and (vi) were related to outbreak investigations or infection control practices. Databases were searched for concepts relating to shoes, footwear, boots, disease transmission, disinfectants and decontamination. A complete list of search strategies can be found in the supplementary materials (Table S1). All full-text articles and abstracts were independently reviewed by two authors and any discrepancies were resolved by consensus.

The software program, REFWORKS (ProQuest, Ann Arbor, MI) was used as a citation manager to manage citations including removal of the internal and external duplicates among the databases. A custom MS Excel workbook (Microsoft Corp, Redmond, WA) for systematic review was designed and used to screen abstracts (VonVille 2015). Two authors independently appraised and abstracted details from all the eligible full-text articles and integrated the findings into a descriptive summary table. Information abstracted from the selected articles for the first objective included author, year of publication, country, study design, study setting, sample size, study procedure and findings (Table 1). For the second objective, information abstracted included author, date of publication, country, study design, mode of decontamination use, intervention and disinfectant efficacy (Table 2). Quality control during article screening process was accomplished by (i) database search conducted by experienced author; (ii) a high Cohen's kappa for agreement between the two authors screening the abstracts; (iii) independent searching of all the abstracts and titles by two authors; (iv) screeners were blinded to the study author, and (v) independent review of all full-text articles by the two authors.

Results

To answer the first objective, 1653 unique citations were identified through database and reference search. Of the 1653 citations, 222 full-text articles were assessed for eligibility. Thirteen articles fulfilled all the criteria and were included in the construction of evidence table. Cohen's kappa of agreement between the two authors was 91% (Cohen's kappa for inter-rater reliability $K = 0{\cdot}91$). The article selection process is outlined through the PRISMA (Preferred Reporting Items for Systematic Reviews) diagram in Fig. 1. To answer the second objective, 122 unique citations were identified of which 19 eligible citations were assessed through full-text search. Fifteen articles met the inclusion criteria and were included in the review. Cohen's kappa of agreement between the two screeners was high ($K = 0{\cdot}96$). The PRISMA diagram for the second review is outlined in Fig. 1.

Shoe contamination in the hospital environment

The first objective evaluated studies that assessed prevalence of infectious agents on shoe surfaces. All 13 articles included in the review were observational studies primarily cross-sectional ($n = 10$) or longitudinal ($n = 3$) (Chambers *et al.* 2009; Laube *et al.* 2014; Rückerl *et al.* 2014). All studies were published in English between 1994 and 2015 from the United States or European

Table 1 Studies with evidence of pathogens on shoe surfaces

Author(s) (Year)	Country	Study design	Study location	Number of samples	Collection procedure	Findings
Hospital settings						
Paduszyńska *et al.* (2014)	Poland	Observational study	Hospital	11	Shoe soles of physicians collected before and after rounds	56% of shoes before rounds and 65% after rounds were contaminated with MRSA or *Enterococcus faecalis*
Amirfeyz *et al.* (2007)	USA	Observational study	Hospital (operation theatre)	100	Samples from everyday wear shoes and theatre shoes (50, each)	Everyday wear shoes: 88% tested positive for at least 2 bacterial species. Theatre shoes: 48% tested positive for at least 1 bacterial species
Agarwal *et al.* (2002)	UK	Observational study	Hospital (Operation theatre)	54	Upper surface and soles of boots used in operating rooms	Majority of the boots of surgical staff were contaminated with significant numbers of bacteria
Community settings						
Schoder *et al.* (2015)	Vienna	Observational study	Community	373	Shoe swabs sampled from Vienna, Austria	40–80% of shoes contaminated with *Listeria monocytogenes* depending on sole tread
Alam *et al.* (2014)	USA	Observational study	Household	127	Shoe bottoms collected from households	39·7% of shoe bottoms contaminated with *Clostridium difficile*
Rückerl *et al.* (2014)	Austria	Observational study	Cheese processing facility	1284	Shoe bottoms	48·4% of shoes were contaminated with *L. monocytogenes*
Laube *et al.* (2014)	Germany	Observational study	Broiler fattening farms	80	Boots used on the farm	28·8% of boot swabs were positive for ESBL/AmpC-producing *Escherichia coli*
Eisenberg *et al.* (2013)	Germany	Observational study	Dairy herds	130	Boots from areas around MAP infected and noninfected herds	MAP infected herd: 90·6% of boots MAP positive. MAP noninfected herd: 1·5% of boots MAP positive
Pitkin *et al.* (2009)	USA	Observational study	University of MN research farm	140	Boots from PRRSV-positive and PRRSV-negative pig farms	PRRSV -positive boots of all samples in PRRSV-positive farms and none in PRRSV-negative farms
Chambers *et al.* (2009)	Alaska	Observational study	Community	56	Presterilized boots sampled after a walk through town	Coliform and *E. coli* presence in 70% and 40% of boots respectively
Ramabu *et al.* (2004)	New Zealand	Observational study	Broiler farms	41	Driver's and catcher's boots	54·3% of driver's boots and 66·7% of catcher's boots positive for *Campylobacter jejuni*
Curry *et al.* (2002)	Antarctica	Observational study	Voyage ship	72	Swabs collected prior to landing, immediately after return to ship and after washing in seawater	15 of 72 pairs contaminated with 20 separate bacterial isolates
Haddock and Nocon (1994)	USA	Observational study	Community	58	Shoe samples taken from public library, public playground and, government office building	6·9% of the samples tested positive for *salmonella* species.

PRRSV, porcine reproductive and respiratory syndrome virus; ESBL, extended spectrum beta lactamase; MRSA, methicillin-resistant *Staphylococcal aureus*; HLAR, high-level aminoglycoside resistance; MAP, *Mycobacterium avium paratuberculosis*.

countries. Three studies investigated shoe sole contamination in the hospital setting with the remainder conducted in the community farm and household setting. Among the three studies conducted in the hospital setting, two looked at contamination of shoes at the operation theatre and one looked at physician shoes in the surgery department (Agarwal *et al.* 2002; Amirfeyz *et al.* 2007; Paduszyńska *et al.* 2014). Paduszyńska *et al.* (2014) studied

Table 2 Evidences for disinfection of shoe surfaces using current disinfectants

Author	Country	Study design	Mode of disinfection use	Intervention	Effect of disinfection
Health care facilities					
Marchetti *et al.* (2003)	Italy	Prospective	Decontamination mats containing (3-1 benzoisothiazolin)	Adhesive mats were placed in access areas to the operating rooms	A statistically significant reduction in microbial load was achieved with the use of the mats
Shin *et al.* (1999)	Japan	Prospective	Water retention mat Paper mat Tank-type mat	Sole swab was collected pre- and postintervention	Tank-type mat was superior to paper mat and water retention mat in reducing the bacterial load
Humphreys *et al.* (1991)	USA	Observational study	Over shoes	Operation theatre floor bacterial count measured 2 weeks before and after overshoe use	No significant difference between use or no use of over shoes
Copp *et al.* (1987)	USA	Prospective study	Protective foot wear (polypropylene shoe covers *vs* OR restricted shoes)	Comparison of operating room floor bacterial count using protective foot wear *vs* unprotected street shoes	Protective foot wear reduce bacterial contamination of theatre floors
Dragas *et al.* (1983)	Yogoslavia	Prospective study	Dry adhesive bactericidal mats	Comparison of bacterial count before and after bactericidal mat use	Adhesive mats did not reduce bacterial contamination
Animal care facilities and veterinary hospitals					
Hartmann *et al.* (2013)	USA	Prospective study	Efficacy of phenolic disinfectant -filled foot mats	Mat placed in common use corridor between large and small animal hospital	No significant difference in the number of aerobic bacteria isolated before and after mat placement
Allen *et al.* (2012)	USA	Prospective study	Effectiveness of adhesive mats *vs* shoe covers *vs* contamination control flooring	Contaminations control products compared with use of no product.	Mean bacterial count on heels and soles of footwear significant less ($P < 0{\cdot}05$) with the use of shoe covers compared to adhesive mats or contamination control flooring
Allen *et al.* (2010)	USA	Sampling trial	Disposable shoe covers *vs* Disinfection mats (Virkon*)	Disinfectant filled mat, shoe cover *vs* no product.	Mean bacterial count significant lower with disinfectant mat ($P = 0{\cdot}0015$) and shoe cover use ($P = 0{\cdot}04$) compared to control
Dunowska *et al.* (2006)	USA	Prospective study	Peroxygen-based disinfectant in footbath *vs* foot mats	Swab of untreated and treated boots taken 10 min after each treatment.	Mean bacterial count 1·3–1·4 $\log_{10}$ lower in disinfectant treated boots compared to untreated boots
Amass *et al.* (2006)	USA	Observational study	Mat filled with Peroxygen	Mat placed at entry or exit from the food animal ward.	No significant difference between number of bacteria at entry (before and after mat use). Significant difference in number of bacteria at exit (before and after mat use).
Stockton *et al.* (2006)	USA	Field trial	Rubber over boot + foot mat (quaternary ammonium *vs* Peroxygen) *vs* No restriction on footwear + Peroxygen footbaths/mats	Disinfection protocols were compared using samples collected from floor surfaces pre- and post-trial	No significant difference between the three protocols. The difference in number of bacteria recorded is <1 $\log_{10}$.
Morley *et al.* (2005)	USA	Prospective study	Peroxygen foot bath *vs* Quaternary ammonium foot bath *vs* water	Contaminated boots immersed in one of two disinfectant bath for 7 min	Significant decrease in bacterial count (67–78% lower in treated *vs* Nontreated only for Peroxygen foot baths

Table 2 (*Continued*)

Author	Country	Study design	Mode of disinfection use	Intervention	Effect of disinfection
Dee *et al.* (2004)	USA	Field trial	Disposable plastic boot *vs* disposable boot + boot bath (6% sodium hypochlorite) *vs* polygrate flooring	Sole swab taken	Disposable boots and bleach containing boot baths were efficient to prevent mechanical transmission of porcine reproductive and respiratory syndrome virus (PRRSV)
Others					
Langsrud *et al.* (2006)	Norway	Cross-sectional study	Disinfection foot bath containing chlorine in food industry	Samples taken from used disinfectant of foot bath and swab from corners	Various bacterial microflora were found in 9 of 12 footbaths
Amass *et al.* (2006)	USA	Prospective study	USDA-approved footwear disinfection protocol *vs* Novel protocol	Both protocols were tested on airplane passenger in contact with livestock.	Significant difference between novel and USDA protocol ($P < 0{\cdot}0001$)

*Virkon: Oxone (potassium peroxymonosulfate), sodium dodecylbenzenesulfonate, sulfamic acid and inorganic buffers.

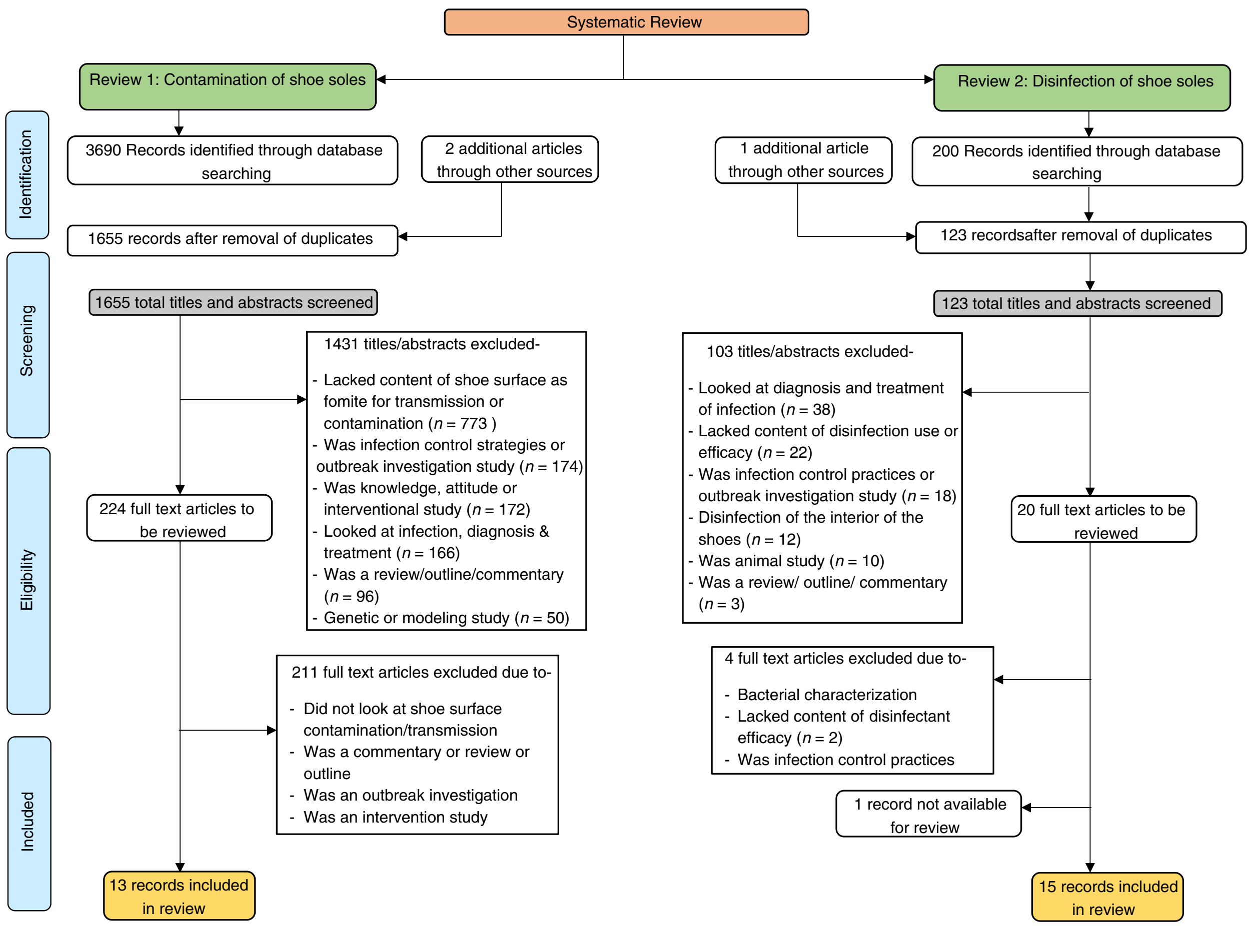

Figure 1 PRISMA flow diagram for systematic review.

contamination of shoe soles of physicians before and after patient care rounds using swabs samples processed through the National Coordination center of Poland. Methicillin-resistant *Staphylococcus aureus* (MRSA) and *Enterococcus faecalis* were identified on the shoe soles of 56% of physicians before rounds and 65% after rounds.

Amirfeyz *et al.* (2007) looked at bacterial contamination of the operating theatre shoes at beginning and end of the working day compared to outdoor shoes. They reported that 88% of outdoor shoes were positive for at least two pathogenic bacteria. Around 48% of operating room theatre shoes were also positive for at least one pathogenic species, most commonly coagulase-negative staphylococcus. Agarwal *et al.* (2002) investigated bacterial isolation and quantification from operating room theatre boots and found that most operating boots were contaminated with normal human microflora including staphylococcus, streptococcus and bacillus species.

Shoe contamination in the community

Studies done in the household and public places also reported similar contamination of shoes. Alam *et al.* (2014) found that 39·7% (25 out of 63) of shoe bottoms collected from household were contaminated with *Cl. difficile.* Schoder *et al.* (2015) looked at prevalence of *Listeria* species on shoe bottom samples. *Listeria monocytogenes* was prevalent in 40–80% of shoes of facility patrons (Schoder *et al.* 2015). Contamination rates did not differ based on type of shoe (winter boots, hiking boot, sports shoes); however, deep tread shoes had higher contamination rates than smooth treads. Haddock and Nocon (1994) investigated prevalence of Salmonella species on shoe bottoms. Two of 22 samples collected from children shoes and 2 of 15 samples from adult shoes were found to be positive for *Salmonella* species.

Chambers *et al.* (2009) conducted a longitudinal study at a rural Alaskan community to determine the mechanism of transport of faecal contamination to the community. The study participants walked a predetermined pathway starting with sterilized boots and concluded walking by stepping onto a clean piece of linoleum. At the end of the walk, 70% of boots were contaminated with coliforms of which approx. 40% of boots were contaminated with *Escherichia coli*. Coliforms were transferred from boots to flooring in 50% of walks and 10% of cases for *E. coli*.

Shoe contamination among animal workers

Detection of microbiological contaminants on the soles of the boots of individuals working in and around animal farms, broiler farms, dairy herds and research farms has also been demonstrated (Curry *et al.* 2002; Ramabu *et al.* 2004; Pitkin *et al.* 2009; Eisenberg *et al.* 2013; Rückerl *et al.* 2014). More than 50% of the boots and shoes of catchers and drivers in chicken broiler farms, 48% of boots of workers in cheese facilities and 45·4% of boots swabs from dairy farms were found to be contaminated with *Campylobacter jejuni*, *L. monocytogenes* and *Mycobacterium avium paratuberculosis* respectively (Ramabu *et al.* 2004; Rückerl *et al.* 2014).

Decontamination strategies for shoe soles

The second objective of the systematic review investigated disinfectant strategies for shoe bottoms (Table 2). Studies were identified that investigated decontamination strategies in health care facilities and animal care facilities. Decontamination strategies included chemical disinfectants, shoe covers, overboots, floor mats and contamination control floorings.

Chemical decontamination strategies

Two studies performed in health care setting compared the efficacy of chemical filled mats to standard procedures. Marchetti *et al.* (2003) conducted a study using decontaminating mats consisting of layers of adhesive sheets supplemented with 3-1 benzoisothiazolin placed in hallways leading to an operation room theatre. There was a significant reduction in bacterial load after placement of the mats compared to routine procedures ($P < 0{\cdot}001$). However, drying up of the disinfectants from the mat may affect the decontamination action (Ohta *et al.* 2000). Shin *et al.* compared bacterial density before and after 0·2% benzylkonium was sprayed on water retention mats, paper mats and tank-type mats placed at the entrance of hospital wards (Ohta *et al.* 2000). The decontamination rate was found to be highest for tank-type (83 ± 12% reduction in bacterial count) compared to the water retention-type (75 ± 9%) and paper-type mats (68 ± 12%).

Chemical disinfectants have also been tested in animal care facilities. Hartmann *et al.* (2013) reported that phenolic disinfectant-filled mats did not significantly reduce bacterial load. The efficacy of peroxygen disinfectant has also shown variables results between studies (Morley *et al.* 2005; Dunowska *et al.* 2006). Dunowska *et al.* (2006) found that irrespective of use of foot bath or foot mat, peroxygen disinfectant was able to reduce the bacterial count by 1·3–1·4 $\log_{10}$. Morley *et al.* (2005) also demonstrated a 67–78% reduction in mean bacterial concentration in boots treated with peroxygen compared to untreated boots. However, studies done by Amass *et al.* (2006) and Stockton *et al.* (2006) found that peroxygen disinfectant efficacy varied based on a variety of factors. Stockton *et al.* (2006) found that the number of bacteria found in the floors of an animal hospital were not affected by peroxygen disinfectant to a significant extent. Likewise, Amass *et al.* (2006) demonstrated that peroxygen disinfectant mat at an entry to an animal hospital ward was not effective to reduce bacterial load. Two other studies (Morley 2002; Stockton *et al.* 2006) also demonstrated that quaternary ammonium boot baths or boot mats were not effective in reducing bacterial count in veterinary hospitals. Scott *et al.* tested four strategies including sodium hypochlorite decontamination to prevent the mechanical transfer of porcine reproductive and respiratory syndrome virus (PRRSV) (Dee *et al.* 2004). Boot baths containing 6% sodium hypochlorite was efficient to prevent the transmission of PRRSV (Dee *et al.* 2004). However, Langsrud *et al.* (2006) reported that chlorine containing foot baths may act as a source of bacterial contamination in food factories. Allen *et al.* (2010) reported that Virkon (a chemical mixture of oxone, sodium dodecylbenzenesulfonate, sulfamic acid and inorganic buffer) was able to significantly decrease the mean bacterial count ($P = 0{\cdot}0015$).

Other decontamination strategies

Two studies performed by Allen *et al.* (2010, 2012) as well as Copp *et al.* (1987) demonstrated that shoe covers may be effective in reducing bacterial contamination. Disposable boots were also shown to be efficient to prevent mechanical transmission of PRRSV (Dee *et al.* 2004). However, these results conflicted with other studies using shoes and overboots in which overboots were not effective at reducing bacterial counts on floor surfaces (Humphreys *et al.* 1991; Stockton *et al.* 2006). Similar results were shown with dry adhesive mats in which two studies found dry adhesive mats to be ineffective to reduce the bacterial contamination (Dragas *et al.* 1983; Allen *et al.* 2012) Finally, Amass *et al.* tested a USDA-approved protocol for shoe decontamination consisting of brushing and dipping shoe sole in Virkon for decontamination in airports against a novel protocol (brushing sole, wiping with Virkon and drying with paper towels). The novel protocol was found to significantly reduce the bacterial concentration compared to the UDSA-approved protocol ($P < 0{\cdot}0001$) (Amass *et al.* 2006).

Discussion

Despite a high likelihood of microbiological contamination, shoes are not often considered a vector for infectious diseases transmission. A search identified no systematic review of this topic. Thus, the objectives of this systematic review was to assess the evidence that shoe surfaces are vectors for infectious disease transmission and evaluate the evidences for the efficacy of disinfectants to decontaminate shoe surfaces. After a thorough bibliographic search, studies were identified that showed high rates of bacterial shoe sole contamination in the hospital-, community, and animal worker areas. Although a number of chemical and nonchemical decontamination strategies have been tested, none have shown to be able to consistently decontaminate shoe bottoms. Strengths of this study include a strong methodological approach to the systematic review including multiple bibliographic databases searched by two independent reviewers. To the best of our knowledge, this is the first study ever to systematically review the literature to assess shoe soles as a vector for infectious diseases transmission. Many types of healthcare-associated pathogens were identified including MRSA, *Enterococcus*, *Cl. difficile*, multidrug-resistant Gram-negative species, to name a few. Although a number of chemical and nonchemical disinfectant strategies were employed, none were able to consistently decontaminate shoe bottoms.

Transmission dynamics of infectious diseases is a global problem (Knetsch *et al.* 2013). Studies that range from cattle movements in Uruguay to movements patterns of school children have demonstrated the importance of human movement in infectious diseases (Kucharski *et al.* 2015; VanderWaal *et al.* 2016). The epidemic *Cl. difficile* 027 ribotype was shown to have originated from two distinct lineages which then spread globally by unknown reasons (He *et al.* 2013). On a smaller scale, similar sublineage strains have been shown to be present in distinct locations in London, England (Cairns *et al.* 2015). As we have previously shown that *Cl. difficile* strains including ribotype 027 is present on shoe bottoms (Alam *et al.* 2014), it is a viable hypothesis that shoe soles could be a vector for worldwide transmission of infectious diseases. Similar transmission dynamics are as likely on a microscale within health care institutions with populations at risk for healthcare-associated infections. In this review, many of the most common microbiologic pathogens including MRSA, *Enterococcus*, *Cl. difficile*, and Gram-negative bacteria were identified on shoe soles. Disease transmission of MRSA has been shown to be increased in hospitals with increased patient sharing between hospitals as opposed to hospitals that do not share patients (Chang *et al.* 2016). Movement of MRSA from hospital to hospital was commented to be likely due to patient spread; however, it is possible that shoe bottoms could have also accounted for the vector spread based on findings from this meta-analysis. All of these hypotheses will require generation of a transmission dynamic model from the bottoms of shoes to a patient. All of these data should be tested in the context of proper hand washing and other proven infection control practices. The study by Chambers *et al.* (2009) identified in this review revealed that microbiological pathogens on shoe bottoms could be transferred to a linoleum floor. From the floor, it is plausible that air currents, human movements over the floor and other factors that aerosolize or provide an airborne opportunity for the organism may occur, thus causing human infections via inhalation, horizontal or cross-contamination from other persons, clothing or equipment that the organism resettles upon. It is furthermore plausible that due to the existence of these microbiological pathogens on shoe soles that the rapid spread of these organisms in the health care environment can be directly related to the organisms on floors getting picked up and carried by shoe soles and retransferred to floors in other areas by human movement. This potential transmission dynamic requires validation. Shoes become contaminated from a dirty floor and parallel methods to decontaminate flooring is also required. Perhaps most surprising finding from this study was the relative lack of consistent efficacy to decontaminate shoe bottoms using either chemical or nonchemical strategies. Although, most strategies had variable success, the complexity of maintaining sterility of the disinfectant strategy appeared to be the most complex and difficult to optimize component of the decontamination strategy. For example, Langsrud *et al.* (2006) reported that chlorine-containing foot baths may act as a source of bacterial contamination in food factories. Taken together, these results suggest the shoe soles can be a likely vector for infectious diseases transmission and an effective decontamination strategy is direly needed.

This study has certain limitations. We limited our search strategy to articles identified from Ovid Medline, PubMed and Embase. Articles indexed in other databases may not have been included in this review. Studies were heterogeneous in regard to sampling strategy, population, disinfectant type used. Thus, a meta-analysis of our data was not possible. However, a consistently high rate of shoe sole contamination was noted in all studies. Future studies need to better understand the probability of transferring microbiological pathogens from the shoes to flooring surfaces or other areas that may impact the disease transmission model. Last, an effective decontamination strategy for shoe soles is urgently needed.

Conclusion

In conclusion, a high prevalence of microbiological pathogens was identified from shoe soles studied in the health care, community and animal worker setting. An effective decontamination strategy for shoe soles was not identified. Studies are needed to assess the potential for contaminated shoes to contribute to the transmission of infectious pathogens.

Conflicts of Interest

This study was funded by a research grant from Healthy Sole, Inc. All authors declare they have no other competing interests.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1 Supplementary materials.