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Major article

Application of quantitative microbial risk assessment for selection of microbial reduction targets for hard surface disinfectants

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Background: This quantitative microbial risk assessment (QMRA) included problem formulation for fomites and hazard identification for 7 microorganisms, including pathogenic *Escherichia coli* and *E coli* 0157:H7, *Listeria monocytogenes*, norovirus, *Pseudomonas* spp, *Salmonella* spp, and *Staphylococcus aureus*. The goal was to address a risk-based process for choosing the $\log_{10}$ reduction recommendations, in contrast to the current US Environmental Protection Agency requirements.

Method: For each microbe evaluated, the QMRA model included specific dose-response models, occurrence determination of aerobic bacteria and specific organisms on fomites, exposure assessment, risk characterization, and risk reduction. Risk estimates were determined for a simple scenario using a single touch of a contaminated surface and self-inoculation. A comparative analysis of $\log_{10}$ reductions, as suggested by the US Environmental Protection Agency, and the risks based on this QMRA approach was also undertaken.

Results: The literature review and meta-analysis showed that aerobic bacteria were the most commonly studied on fomites, averaging 100 colony-forming units (CFU)/cm^2. *Pseudomonas aeruginosa* was found at a level of 3.3×10^{-1} CFU/cm^2; methicillin-resistant *S aureus* (MRSA), at 6.4×10^{-1} CFU/cm^2. Risk estimates per contact event ranged from a high of 10^{-3} for norovirus to a low of 10^{-9} for *S aureus*.

Conclusion: This QMRA analysis suggests that a reduction in bacterial numbers on a fomite by 99% (2 logs) most often will reduce the risk of infection from a single contact to less than 1 in 1 million.

The currently available test methods for assessing the efficacy of hard surface cleaners were developed without the advantage of knowing the numbers and types of organisms that can be detected on fomites using today's microbiological tools. The US Environmental Protection Agency (EPA) has published efficacy requirements for the concentrations of test organisms required in disinfection testing protocols to achieve nondetection or targeted log reductions without a well-articulated risk-based reduction rationale supported by data. The application of quantitative microbial risk assessment (QMRA) frameworks and models over the last several decades have provided approaches for the control of infectious agents in water and food. For example, QMRA has been used to assess the treatment technology goals for reducing virus and parasites to acceptable levels in drinking water[1] and to determine risk criteria for pathogens, such as *Salmonella* spp, in certain foods.[2] QMRA also provides a mechanism for developing technically informed disinfection goals for surface hygiene and safety.[3,4]

Fomites have been recognized as important in the spread of infectious disease, particularly through fomite–hand interactions and are common concerns in environments of high contacts (touches) with such pathogens as norovirus, influenza, and rotavirus, as well as and methicillin-resistant *Staphylococcus aureus* (MRSA).[5-14] Fomites have been associated with infectious disease outbreaks in such venues as cruise ships, restaurants and nursing homes,[15] schools,[16,17] daycare centers,[18] and gyms.[19,20]

Cleaning, sanitation, and disinfection have different goals when treating surfaces for the removal of dirt and specific requirements for controlling microorganisms. The US EPA Pesticide Program has defined the products used for these purposes in 5 descriptive categories: nonfood contact surface sanitizers, limited disinfectants, general/broad-spectrum disinfectants, medical environment

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disinfectants, and food contact surface sanitizers (nonhalide products). Table 1 describes the EPA requirements and associated surrogate organisms for use in testing for each of these categories, including *S aureus*, *Klebsiella pneumonia*, *Enterobacter aerogenes*, *Salmonella enterica* ser. *choleraesuis*, *Pseudomonas aeruginosa*, and/or *Escherichia coli*.

The present study had 2 goals: (1) to provide background data on microbial surface contamination reported in studies for households, restaurants, work offices, hospitals, schools and daycare centers, and (2) to provide a data-based assessment of the risk associated with enteric and skin pathogens via exposure to contaminated fomites and the levels of risk reduction achieved by treatment within the 5 EPA product categories. Seven pathogenic organisms with dose-response datasets were selected for developing a QMRA to examine the risk reduction from sanitation and disinfection of fomites: pathogenic *E coli*, *E coli* 0157:H7, *Listeria* spp, norovirus, *Pseudomonas* spp, *Salmonella* spp, and *S aureus*.

Problem formulation and hazard identification

Fomites refer to inanimate structural materials found mostly in indoor environments (ie, buildings) that are part of our everyday lives. Examples include walls, floors, chairs, tables, books, toys, mobile phones, computer keyboards, door handles, and bedrails. Fomites also include surfaces used for food preparation, such as countertops and sinks.

Two groups of hazards and associated exposure pathways involving fomites were evaluated in the present study. The first group comprised enteric bacteria and viruses that spread via fecal-hand-fomite-hand-mouth pathways, including pathogenic *E coli*, *E coli* O157:H7, *Listeria*, *Salmonella*, and norovirus. Norovirus also can be found in vomitus, and *Listeria*, *E coli*, and *Salmonella* can regrow in foods and be shed in the feces of animals (eg, pets). The second group were skin-borne and eye infections associated with staphylococci and *Pseudomonas,* respectively, which spread by hands to skin or eyes from sources including natural flora of the skin, nasal passages, pets, water, soil and foods.

E coli, a gram-negative bacterium, is one of the most diverse groups of organisms that commonly inhabit the intestines of warm-blooded animals. These bacteria serve as fecal indicators, because they are always present in feces in fairly large numbers. There are 5 classes of pathogenic *E coli* associated with diarrhea, including enterotoxigenic (ETEC), enteroinvasive (EIEC), a subgroup of Shiga toxin—producing *E coli* known as enterohemorrhagic (EHEC), enteropathogenic (EPEC), and enteroaggregative (EAEC). *E coli* O157:H7, a member of the EHEC group,[21] causes hemorrhagic colitis (inflammation of the intestinal wall), and the toxins cause damage to endothelial cells in the kidneys, thereby inhibiting the organs' ability to function.[22] Young children and elderly adults can develop hemolytic uremic syndrome (HUS) as a result of exposure to *E coli* O157:H7, a condition that can lead to serious kidney damage and even death.[23]

Listeria monocytogenes is receiving much attention owing to the increasing numbers of food-associated outbreaks. One such outbreak was associated with cantaloupe in 2011.[24] A total of 146 persons from 28 states were infected with *L monocytogenes*, and 30 deaths were reported. One woman who was pregnant at the time of illness had a miscarriage. According to the Centers for Disease Control and Prevention (CDC), 3-4 food-borne outbreaks occur and approximately 800 cases are reported each year in the United States. Common high-risk foods include deli meats, hot dogs, and Mexican-style soft cheeses made with unpasteurized milk. Sprouts were associated with an outbreak in 2009, and in 2010 an outbreak was caused by celery, even though produce is not a common food associated with *Listeria*.[24] One of the main risk factors for *Listeria* is

Table 1
US EPA product categories and goals for microbial reductions associated with sanitizers and disinfectants*(gram stain + or −)

Category	Nonfood contact surface sanitizer	Limited disinfectant	General/broad-spectrum disinfectant	Medical environment disinfectant	Food contact surface sanitizer (nonhalide products)
Claims allowed	Sanitizer: kills 99.9% (3 log 10) germs Kills [organisms tested]	Limited disinfectant against [organism] Kills [organism tested]	Disinfectant, kills germs Kills [organisms tested]	Disinfectant antibacterial: kills germs Kills [organisms tested]	Sanitizer; kills 99.999% (5 $\log_{10}$) of germs on food contact surfaces Kills [organism tested]
Test method (product can be tested neat or dilute)	Sanitizer test for nonfood contact surfaces	Use dilution test (liquids) or germicidal spray products test	Use dilution test (liquids) or germicidal spray products test	Use dilution test (liquids) or germicidal spray products test	Germicidal and detergent sanitizer test
Performance standard	99.9% (3 log 10) reduction in 5 min	100% kill* in 10 min	100% kill* in 10 min	100% kill* in 10 min	99.999% (5 log 10) reduction in 30 s
Target organisms* (to these can be added claims against odor-causing bacteria (eg, *E coli*, *Proteus mirabilis*))	Two organisms: *S aureus* (+) and *K pneumoniae* (−) or *Enterobacter aerogenes* (−)	One organism: *Salmonella choleraesuis* (−) or *S aureus* (+)	Two organisms: *S choleraesuis* (−) and *S aureus* (+)	Three organisms: *S choleraesuis* (−), *S aureus* (+), and *P aeruginosa* (−)	Two organisms: *E coli* (−) and *S aureus* (+)

For *Salmonella*, the 100% kill of a minimum target of 10^4 (4 log 10).
For *Staphylococcus*, the 100% kill of a minimum target of 10^5 (5 log 10).
*100% kill of up to a targeted concentration of 10^7 (7 log 10).

contamination of food-contact surfaces, with transfer to foods and often subsequent regrowth of the pathogen in the food under temperature abuse (eg, food not held at the appropriate temperature).

Norovirus is a calicivirus comprising 5 genogroups, 3 of which contain human strains associated with disease. Norovirus causes an estimated 21 million cases of illness in the United States each year,[25,26] including both outbreaks and sporadic cases. There were 232 outbreaks from 1997-2003, 3% of which were attributed to water sources and 50% to food sources.[27]

P aeruginosa is the most common cause of eye infections among contact lens wearers.[28] Serious infections can result in vision loss. In 1989, the annualized incidence of microbial keratitis in the United States was estimated as 4.1 per 10,000 daily soft contact lens wearers and 20.9 per 10,000 soft contact lens wearers.[29]

Salmonella bacteria are gram-negative, and many species have been associated with disease in humans. Diarrhea, abdominal cramps, and fever are the most common symptoms, which can last 4-7 days (with an 8- to 72-hour incubation time). *Salmonella* causes an estimated 1.2 million cases of illness per year in the United States.[30]

S aureus is a common gram-positive bacterium associated with the normal skin flora; however, some strains are capable of causing skin infections, and those starins that carry resistance to antibiotics (especially methicillin-resistant *S aureus* [MRSA]) are the major problem associated with nosocomial and community infections.[31] A major survey by Klevens et al[32] reported 8,987 cases per year, including 58.4% associated with health care settings and 26.6% that were community-based.

Enteric bacteria are most commonly found in kitchen and bathroom areas.[33,34] Typically the occurrence and concentrations of enteric bacteria may be greater in the kitchen than the bathroom area because of the growth of these bacteria in cleaning tools (eg, sponges, dish cloths),[35] as well as from foods (eg, raw meat products). When used, these tools spread coliform bacteria around the surfaces that they contact.[36] In addition, some coliform bacteria are highly resistant to drying. *Salmonella* will grow in cleaning tools and in one study were found in 15% of sponges and dishcloths used in the kitchen.[35] *Pseudomonas* bacteria grow well in moist environments, including sinks, refrigerators, and taps, and are often found in high concentrations in these environments.[35,37] *Staphylococcus* spp and micrococci are common in indoor environments because they are shed by the skin and nose. Taking all of these factors into account explains why coliform and other enteric bacteria are common in the domestic environment.

More information is needed on specific pathogen excretion rates by infected individuals, as well as concentrations in pets, raw food sources (eg, chicken), and occurrence on fomites from these sources. Subsequent studies on the occurrence as well as the duration of contamination would provide better information on the distribution of enteric pathogens on fomites in key environments.

METHODS

Dose-response

Dose-response models for this QMRA were obtained from an analysis of the published literature from the online QMRA wiki: http://wiki.camra.msu.edu/index.php?title=Quantitative_Microbial_Risk_Assessment_(QMRA)_Wiki. These models are mathematical best-fit analysis of animal or human experimental feeding studies. These models depict the probability of a response (ie, infection or disease, or mortality) given a particular pathogen dose. Each of the dose-response models contain parameter(s) optimized to data specific to the pathogen of interest. Thus, these models provide a yardstick for assessing the relative potency of a pathogen, and describe the dose and probability of disease or infection after ingestion, inhalation, or skin/eye contact.

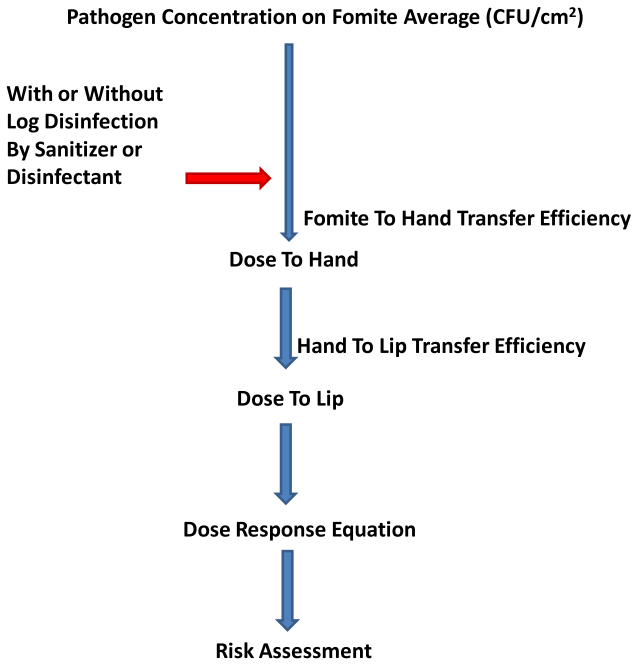

Fig 1. Scenario for calculating exposure and risk associated with fomite contamination. Exposure to microorganisms on fomites was modeled as associated with a single touch of the fomite, followed by transfer to the mouth.

Occurrence and transfer efficiency of microorganisms on fomites

Our literature search focused mainly on 2 areas, transfer efficiencies and surface occurrence data. The transfer efficiency search centered on finding existing data regarding the transfer of either surrogate organisms or pathogenic organisms from hard, nonporous fomites to hands. Another focus of the transfer efficiency search was the percentage transfer of organisms from skin to skin or hand to mouth/eye. In addition, the occurrence of microbial hazards on fomites was summarized from the peer-reviewed literature. This included data on surrogate organisms, indicators, and/or pathogenic organisms on hard, nonporous fomites. The goal was to summarize and standardize the average concentrations and ranges of microbes found per square centimeter of surface area.

A total of 49 published journal articles were finally selected for analysis in this study (see Supplemental References). An additional 20 project reports and draft manuscripts (Supplemental References), most supplied by Dr Charles Gerba (University of Arizona), were analyzed as well. All of the articles were entered into summary forms to collate the articles into a uniform dataset. The summary forms were further combined into 3 summary sheets for quantitative, qualitative, and transfer efficiencies. A quantitative statistical analysis was conducted to determine distributions for different microbes in various venues.

Exposure assessment

A simple scenario was developed for addressing the exposure of an individual to a contaminated fomite (Fig 1), which could then include reduction of the dose via either sanitation or disinfection of the surface (or via handwashing, which was not addressed in this

analysis). Nonporous fomites were considered in this particular QMRA for fomite-mediated disease transmission because of their greater ability to transfer pathogens to human hands (28%-66%) compared with porous fomites (<0.01%).[34]

Key assumptions for this QMRA included the following:

- Average doses, as described in the occurrence section of this article represented by bacterial CFU or virus plaque- forming units (PFU)/cm^2, were used to calculate exposure without regard for the spatial distribution of the microbe in the indoor environment, number of people using the environment, and likelihood that an individual would touch the areas where the microbes had been deposited.
- Transfer efficiencies from the fingertip to the eyes, nose, and mouth were assumed to be equal, with the amount transferred at that point considered the dose. Maximum transfer rates were used.
- Die-off of the pathogens over time was not considered. This seems reasonable because in adults, hand to nose, mouth, or eye touches occurred an average of once every 3.75 minutes.[38]

Persistence in the indoor environment can be important; however, it was not considered in this QMRA, because no time element was included in the exposure scenario. It was assumed that microbes were recently deposited onto the fomites and that exposure occurs regardless of reductions in concentrations over time. Thus, sanitation and disinfection were the sole focus of the risk reduction in the present study, as it is in the EPA protocols for evaluating the various categories.

Calculating the risk of infection

The risk of infection was computed using either an exponential dose-response model,

$$\text{risk} = 1 - \exp(-rd)$$

where r is a model parameter and d is the dose (calculated as described above), or a beta-Poisson model,

$$\text{risk} = 1 - \left[1 + \frac{d}{N_{50}}\left(2^{\frac{1}{\alpha}} - 1\right)\right]^{-\alpha}$$

where N_{50} and α are model parameters.

The model form (beta-Poisson or exponential) and parameters were selected based on a review of the literature, most of which is available in summary form on the QMRA wiki: http://wiki.camra.msu.edu/index.php?title=Quantitative_Microbial_Risk_Assessment_(QMRA)_Wiki.

A target of a 1 in 1 million (10^{-6}) risk of infection per touch was set as the safety goal, and a target pathogen concentration needed to reach this risk was then calculated using the dose-response functions. This target is comparable to a daily risk acceptable for drinking water. The target concentration was then compared with typical fomite concentrations for each pathogen. In cases where the typical concentration was below the target concentration, no disinfection would be needed to achieve the safety goal. In cases where the typical concentration exceeded the target concentration, the required reduction fraction was calculated as follows:

$$\text{Reduction fraction} = 1 - (\text{target concentration}) / (\text{fomite concentration})$$

Numerous uncertainties and assumptions are associated with these types of QMRAs; however, to be conservative, we used the most potent dose-response functions and maximum transference rates, with average concentrations on fomites (without nondetects) used in the calculations. As mentioned earlier, inactivation of the pathogens was not considered. Often in risk management strategies, a conservative approach is taken to provide buffers or additional levels of safety accounting for both uncertainty and variability in the data, in an effort to protect the public. Safety factors associated with the use of QMRA for drinking water have not been considered previously. This issue is addressed in more detail in the Discussion section.

RESULTS

Dose-response

The potency of various pathogens can be compared using the dose necessary to achieve 50% infection (ID_{50}) of the population exposed to that concentration of pathogen. The lower the ID_{50}, the more infectious the pathogen. Particularly at low doses, this value is important for transmission through fomites. The ID_{50} was 2.11E+06 for *E coli*, 2.10E+06 for *Listeria*, 6.60 E+04 for *Pseudomonas*, and 2.36 E+04 for *Salmonella*. The model of Teunis et al[39] for EHEC 0157:H7 instead of the model on the wiki was chosen for this QMRA, because it was fitted from outbreak data and was much more potent. The best-fitting parameters were chosen for children to provide greater protection. A rotavirus model was used for norovirus assessment because of the inadequacy of data associated with norovirus dose-response studies.

S aureus is not represented by an ID_{50} because the infectious dose is related to an initial dose combined with a growth rate associated with colonization of the skin. The dose-response was examined with an average of 12 hours of growth (range, 6-24 hours) before taking a shower (with the 24-hour period used to obtain maximum bacterial growth), and thus is not a traditional dose-response formulation. This growth model fitted an initial decay of the inoculation dose of staphylococci with an exponential growth phase followed by a plateau phase, the latter corresponding to the maximum density of the organism over a skin exposure time range.[40] The modeled equation has no analytical solution, and thus a numerical analysis was conducted to generate time-dependent results given the inoculated dose. The resulting revised dose information was then used in the exponential dose-response model to determine the risk of infection after exposure to staphylococci.

Occurrence and transfer efficiency of microorganisms on fomites

Fig 2 shows a graphic representation of descriptive statistics for different microbes in various venues. Aerobic bacteria, the most numerous, were detected at an average level of 100 CFU/cm^2. The level of total coliform bacteria was similar, at an average of 450 CFU/cm^2, whereas that of fecal coliform was approximately 100-fold lower, at 2.7 CFU/cm^2. The average level of streptococci was similar to that of total coliform bacteria at 140 CFU/cm^2. Given the wide range reported in the various studies, the levels of aerobic bacteria did not differ significantly; the broad overlap is evident in Fig 2. Enterobacteriaceae averaged 4.4×10^{-1} CFU/cm^2; *E coli*, 5.7×10^{-2} CFU/cm^2; *Staphylococcus* spp, 11 CFU/cm^2; and *Pseudomonas* spp, 38 CFU/cm^2. However, the more specific the species of microbe (pathogen), the lower the average concentration found on fomites; for example, *P aeruginosa* and MRSA were detected at average levels of 0.33 CFU/cm^{2}and 0.64 CFU/cm^2, respectively. The averages were based only on samples with quantitative data; values below detection limits and zeros were ignored, to address exposure only at sites that were contaminated and required sanitation or disinfection.

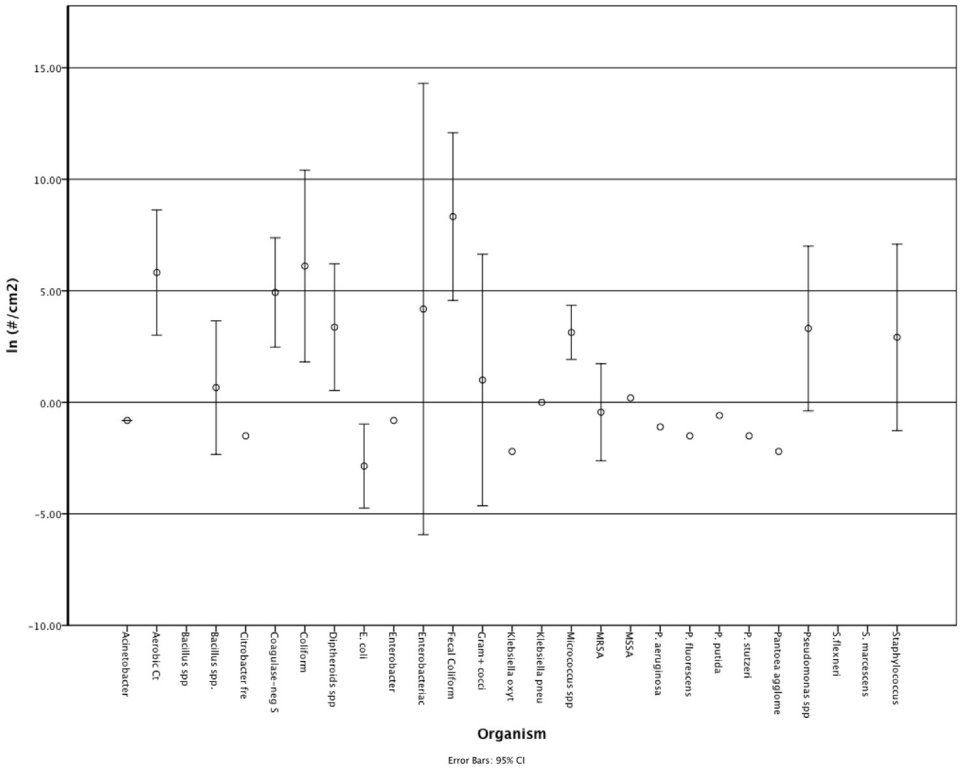

Fig 2. Distribution of bacterial concentrations on fomites, ln (no./cm^2).

The occurrence and concentrations of *L monocytogenes* were based on only 2 studies[41,42] and calculated as 50 CFU/cm^2 on average. Surprisingly, however, very little information was available for surfaces at locations other than food processing facilities. For norovirus, a most probable number was developed based on presence/absence data, and the average was estimated as 0.01 virus/cm^2 (based on polymerase chain reaction and detection of viral RNA) using a maximum likelihood estimate approach.

There are very little reported data on *Salmonella* spp and *E coli* 0157:H7, and the literature does not support a summary of the occurrence of these 2 pathogens on surfaces. Blanch et al[43] compared *E coli* 0157:H7 levels on surfaces and in fecal coliform in domestic sewage and reported a ratio of 1/1,000. In the present study, the same approach was taken to identify levels of *Salmonella* spp and *E coli* 0157:H7 pathogenic species on fomites. Thus, 0.1% of the *E coli* levels reported in the literature was used to estimate these pathogen concentrations, resulting in an average concentration of 5.8×10^{-5} CFU/cm^2.

Fairly large concentrations of common bacteria and fecal intestinal bacteria can be found on hard surfaces when people are present; however, considering that only a certain percentage of individuals are excreting a pathogen at any given time, the pathogen itself will be found at much lower average concentrations. Certain bacteria are capable of growing on key fomites (eg, in kitchen sponges), thus, in certain circumstances, seeding environments may become important reservoirs of bacteria (eg, coliforms, *Listeria*). Although there is no evidence in the literature indicating that pathogens like *E coli* 0157:H7 grow on fomites, and certainly viruses such as norovirus do not grow in these environments, other pathogens, such as *Salmonella* and MRSA, might be able to regrow under specialized conditions.

Exposure assessment

The data used to address the fraction of the microbes (per cm^2) transferred from the fomite to the mouth had 2 pieces.[34,44,45] The first piece in the transfer calculation was the fomite to hand (or finger) surface area touched, and in this case a value of 2 cm^2 (the surface area touched by the hand or tip of a finger) was used. The second piece was the percentage of microbes from that finger transferred to the mouth, nose, or eye. No distinction was made among the 3 sites on the face (mouth, nose, or eyes). Gram- positive and gram-negative organisms, as well as viruses, all had slightly different transfer rates. The median rate of transfer of gram-negative bacteria from fomites to hands was 26% (range, 13%-38%). The median rate of transfer of gram-positive bacteria from fomites to hand was 34% (range, 25%-42%). The median rate of virus transfer from fomites to hand was 51% (range, 33%-68%). The maximum values were used in calculating the dose. The finger to lip or eye transfer rates were 34%, 41% and 34% for gram-positive, gram-negative bacteria, and viruses, respectively.

Risk characterization and risk reduction

Risk estimates ranged from a high of 10^{-3} for norovirus to a low of 10^{-9} for staphylococci for a single touch, with exposure to average concentrations reported in surveys of fomites (Table 2). Pathogenic bacteria were influenced by 2 factors. The first of these factors was the average concentration found on fomites. As mentioned above, there are no data on *E. coli* 0157:H7, EPEC, and *Salmonella* on fomites; thus, it was assumed that these pathogens represented some percentage of the generic *E coli* found on surfaces. This is a significant knowledge gap associated with contamination of the indoor environment. The second factor that influenced risk

Table 2
Probability of infection and risk reductions needed to achieve a safety goal of 1 in 1 million (calculated for each pathogen based on the occurrence and higher range of transfer efficiencies)

Microbe	Average surface concentration, organisms/cm^2	Transfer ratio to hand, mouth	Model and parameters, r or α; N_{50}	Single touch risk	Log reduction (%) to meet safety target*
Enteropathogenic *E coli*	5.8×10^{-5}	0.39, 0.34	Exponential† 3.75E-01	5.6×10^{-6}	0.75 (82%)
E coli 0157:H7	5.8×10^{-5}	0.39, 0.34	Beta-Poisson‡ $\alpha = 0.844$ $\beta = 1.442$	1.5×10^{-4}	2.2 (99.2%)
Listeria	50	0.42, 0.41	Modified beta 1.70E-01 2.10E+06	8.1×10^{-5}	1.9 (98.8%)
Norovirus	0.01	0.68, 0.34	Modified beta§ 2.53E-01 6.17	2.7×10^{-3}	3.44 (99.96%)
Pseudomonas	0.33	0.39, 0.34	Exponential 1.04×10^{-4}	9.1×10^{-6}	None
Salmonella	5.8×10^{-5}	0.39, 0.34	Beta-Poisson 0.23 4,910	1.4×10^{-8}	None
Staphylococci	0.0317‖	NA	Exponential 7.63E-08	2.4×10^{-9}	None

*One per 1 million (10^{-6}) safety goal.
†Based on the most infective *E coli* model.
‡Based on Tenuis et al.[39]
§Based on a rotavirus model, because no adequate model exists for norovirus.
‖Dose from growth of staphylococci on the skin after inoculation and showering 24 hours later.

was the potency of the pathogen itself. Rotavirus served as a model for norovirus, because there is no adequate dose-response model for the human norovirus. This is still the most potent pathogen in the dose-response database. The parameters used in the dose-response analysis were chosen from the datasets yielding the highest estimates of potency providing conservative estimates.

Based on the estimated surface concentrations and exposure scenarios described above, on average a 2-log reduction was sufficient to achieve the 1 in 1 million safety target level (Table 2). However, norovirus required a log reduction of 3.44 to meet this safety target. This safety goal was also used to compare the computed risks associated with microbial reductions proposed for current product categories of sanitizers and disinfectants. For the "proposed reductions nonfood contact surface sanitizer" category, the level of additional safety achieved with the recommended 99.9% reduction in microbial concentration was 1,000-fold for *Pseudomonas*, *Salmonella*, and staphylococci (Table 3). For *E coli* and *Listeria*, the additional level of safety achieved ranged from 8-fold to 180-fold (Table 3A). For the "limited disinfectant; general/broad-spectrum disinfectant" category reduction recommendations, the level of additional safety achieved was 10,000-fold greater than the target of 1 in 1 million for *Pseudomonas*, 100,000-fold greater for *Salmonella*, and 10,000,000-fold greater for staphylococci (Table 3B). For "food contact surface sanitizer (nonhalide products)" reduction recommendations, the level of additional safety achieved was 800-fold to 18,000-fold greater than the target risk for *E coli*, depending on whether this was targeting *E coli* 0157:H7 or just EPEC, and 100,000-fold greater than the target risk for staphylococci (Table 3C).

DISCUSSION

Our analysis suggests that 99% removal is adequate in general circumstances to reduce the risk from fomites to 10^{-6} for a single touch, with no consideration of pathogen die-off in the environment. However, the literature values used here for ambient concentrations of bacteria on surfaces might not be applicable when a person is ill and actively shedding pathogens, or when the bacterial pathogen can regrow on fomites at higher concentrations. In such cases, greater removal may be sought to provide more assurance of safety.

The types of data used in and limitations of the present analysis should be fully understood. An analysis of published and unpublished literature was used for this QMRA developed for 7 pathogens associated with a single touch of a contaminated fomite and hand to mouth or eye transfer. Assumptions included no die-off of the microbe on the fomite or hands. Higher levels of general bacteria, up to 100/cm^2 (for general aerobic bacteria) were detected, but more often concentrations of 1, 0.5, or 0.01/cm^2 were found. The highest concentration of bacteria used for this study was for *Listeria*, at 50 CFU/cm^2, from a single kitchen study. There were no data on *E coli* 0157:H7 or *Salmonella*, and only estimates were used, based on the ratio of generic *E coli* to pathogenic *E coli* found in sewage. Increased understanding of the prevalence of specific pathogens and the concentrations in sources found in the home, kitchen, workplace, and hospital environments is needed with subsequent data on fomites.

Both the concentrations and dose-response assumptions used in this QMRA resulted in this wide range of risk estimates, from a high of 10^{-3} for norovirus to a low of 10^{-9} for staphylococci, for a single touch with exposure to average concentrations found in surveys of fomites.

The additional level of safety provided by the criteria for 3-7 log reductions as specified by the EPA's categories for disinfection goals for surface hygiene and safety provided 8-fold to 10,000,000-fold greater safety compared with that needed to achieve a 10^{-6} risk. This level of safety is similar to that suggested as acceptable for safe drinking water (10^{-4} annual risk, an approximate 10^{-6} daily risk). For viruses and organisms such as *Listeria*, in which sensitive populations are of concern regarding severe outcomes, the target reductions of 99.9% and 99.9999%, respectively, achieved the target 10^{-6} risk. More investigation is warranted of the appropriate targets for safety in key venues, such as nursing homes compared with schools, and after events causing high pathogenic contamination of surfaces, such as contact of surfaces with infected vomit, feces, or blood.

Table 3
Comparison of risks and microbial reductions proposed for current product categories of sanitizers and disinfectants

A. Proposed reductions for non-food contact surface sanitizer (99.9%).

Microbe	Risk - No treatment	Risks associated with product reductions - (99.9%)	Reductions to achieve 10^{-6}	Ratio of % reductions for 99.9% TO: Reductions needed to meet 10^{-6} safety goal (X fold)*
E coli	5.6×10^{-6}	5.6×10^{-9}	82%	180x
E coli 0157H7	1.5×10^{-4}	1.5×10^{-9}	99.20%	8 x
Listeria infections	8.1×10^{-5}	8.1×10^{-8}	98.80%	12 x
Pseudomonas	9.1×10^{-6}	9.1×10^{-9}	0	1,000x
Salmonella	1.4×10^{-8}	1.4×10^{-11}	0	1,000 x
Staphylococci	2.4×10^{-9}	2.4×10^{-12}	0	1,000 x

B. Proposed reductions for limited disinfectant; general/broad-spectrum disinfectant and medical environment disinfectant.

Microbe	Risk - No Treatment	Risks Associated with Product Reductions - (100% of: 10^4, 10^5, 10^7)	Reductions to achieve 10^{-6}	Ratio of % Reductions for the range of 99.99% - 99.99999% TO: Reductions needed to meet 10^{-6} safety goal (X fold)*
Pseudomonas 10^5 (99.999%)	9.1×10^{-6}	9.1×10^{-10}	0	10,000 x
Salmonella	1.4×10^{-8}	1.4×10^{-13}	0	100,000 x
Pseudomonas	9.1×10^{-6}	9.1×10^{-11}	0	100,000 x
Staphylococci 10^7 (99.99999%)	2.4×10^{-9}	2.4×10^{-14}	0	100,000 x
Salmonella	1.4×10^{-8}	1.4×10^{-15}	0	10,000,000 x
Staphylococci	2.4×10^{-9}	2.4×10^{-16}	0	10,000,000 x
Pseudomonas	9.1×10^{-6}	9.1×10^{-13}	0	10,00,0000 x

C. Proposed reductions for food contact surface sanitizer (nonhalide products) 99.999% reductions

Microbe	Risk - No Treatment	Risks Associated with Product Reductions - (99.999%)	Reductions to achieve 10^{-6}	Ratio of % Reductions for the range of 99.99% - 99.99999% TO: Reductions needed to meet 10-6 safety goal (X fold)*
E coli	5.6×10^{-6}	5.6×10^{-11}	82%	18,000x
E coli 0157H7	1.5×10^{-4}	1.5×10^{-11}	99.20%	800 x
Staphylococci	2.4×10^{-9}	2.4×10^{-14}	0	100,000 x

For *Salmonella*, the 100% kill of a minimum target of 10^4.
For *Staphylococcus*, the 100% kill of a minimum target of 10^5.
*Values >1 show the extra level of safety and excess reductions achieved when obtaining the stipulated percent reductions by use of the associated sanitizer for designated surfaces.

Future research is needed to refine this type of QMRA. The data on levels of pathogens on fomite surfaces are extremely limited and often based on polymerase chain reaction studies, in which viability was not assessed or only general bacteria were evaluated.

More data are needed on the following:

- Occurrence (especially when a person is ill and excreting the pathogen)
- Survival and persistence
- Distribution of organisms around a room/office
- Transfer during normal use and touching of fomites.

These data should be obtained with seeded experiments under controlled conditions because random surveys have provided only limited information and are inadequate to fill the gaps needed for QMRA. More data could provide the necessary information to perform dynamic or Monte Carlo QMRA. Time could be used, in which case persistence information would be required.

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