Assessment of benefits from use of antimicrobial hand products: Reduction in risk from handling ground beef

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Abstract

Quantitative microbial risk assessment (QMRA) has been used to estimate the benefits resulting from the use of hand cleansing products (e.g., soaps) containing anti-microbial ingredients. This was done by developing a model for the scenario of hand contact with ground beef during food preparation, considering transference of bacteria to the hands, removal and inactivation by handwashing, and subsequent transference from the hands to the mouth. Organisms of interest in this case study were pathogenic \textit{Escherichia coli} and the particular strain \textit{E. coli} O157:H7. It was found that QMRA could be applied to this problem, and that the antimicrobials provided some quantifiable benefit (i.e., reduced the risk of infection and illness). Benefits from the use of triclosan-containing products were less than from the use of products in which alcohols or chlorhexidine were active ingredients.

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Introduction

Topical antimicrobial products for hands containing a variety of active formulations have been increasingly used among the general public, and represent a growing area for consumer product companies.

It is difficult to confirm the quantitative benefits of such products using classical, direct epidemiological intervention tests due to logistical problems of controlling use behavior in a large number of subjects over a long duration trial. In other personal hygiene applications, the methods of quantitative microbial risk assessment (QMRA) have been useful in estimating levels of risks or benefits difficult to establish by direct epidemiological study (Gibson et al. 1999, 2002). The objective of this work was to demonstrate the applicability of QMRA for estimation of benefits from use of topical antimicrobial hand products.

Routinely the general public wash their hands daily with antimicrobial or non-germicidal products. While it is well known that handwashing is a beneficial public health practice for preventing the spread of infectious diseases (Curtis and Cairncross, 2003) there have been a limited number of studies that have attempted to quantify the benefits of using antimicrobial or non-germicidal hand products in reducing disease
transmission (Early et al., 1998; Hammond et al., 2000; White et al., 2001).

QMRA has been used to evaluate the effectiveness of personal hygiene products in only two previous studies. The first study done (Gibson et al., 1999) suggested that laundering and use of a sanitizing detergent could reduce the probability of disease by approximately 90% and 99%, respectively. The second study (Gibson et al., 2002), predicted that adequate washing of hands after diapering reduces risk.

QMRA has many uses throughout a number of different disciplines. A detailed description of QMRA methods and uses can be found in Haas et al. (1999). Hoornstra and Notermans (2001) discussed how QMRA is used as an important tool for governments when food safety objectives have to be developed in the case of new microbiological contaminants in known products or known microbiological contaminants in new products. Another application shown by these authors is how food companies can use QMRA during product development and hygienic process optimization.

A previous study by Montville et al. (2002) attempted to increase the level of understanding of the various factors that influence hand washing efficacy in the home and foodservice establishments. During this study data were collected from scientific literature and laboratory experiments. These data were then used to develop a quantitative risk assessment model to assess the risk associated with different hand washing techniques. Montville et al. (2002) determined that soap with antimicrobial agents was more effective than regular soap. Furthermore, the literature showed that antimicrobial soap with chlorhexidine gluconate as the active ingredient was more effective than any other antimicrobial active ingredient. Several additional conclusions that were made in this study were: conventional hand washing systems cause an increase in contamination on hands, as opposed to the touch-free system; wearing rings cause a small decrease in the efficacy of hand washing; and hand contact with a contaminated faucet spigot, or use of a hot air dryer are to be avoided to improve hand washing efficacy.

Materials and methods

Scenario considered

In this study we consider the use of antimicrobials following handling ground beef containing either Escherichia coli O157:H7 or other pathogenic (non-O157:H7) E. coli. Bacteria are transferred to the hands following handling. The use of hand cleansers (either without or containing antimicrobial agents) occurs prior to hand to mouth contact with the bacterial laden hands. The bacteria are then ingested and the person is at risk for infection with the organisms. This scenario was selected since it is known that handling ground beef during home food preparation can pose a risk of infection with E. coli, which can be reduced by hand washing and other sanitation practices (Mead et al., 1997).

Required distributions

To perform the risk assessment, data on a number of variables was required. These were obtained from the literature, and after screening for data quality, incorporated into a database and used to develop probability distributions. The following information was required:

- Density of pathogens in ground beef.
- Transference of bacteria from beef to hands.
- Removal or reduction of bacteria by hand washing products (without or containing antimicrobial agents).
- Transference of bacteria from hands to mouth.
- Infectivity of ingested pathogens.

An extensive literature search was completed in order to obtain the necessary data to perform the risk assessment. The first source of data included references currently in the files of the investigators that are available in the open literature. The second source was from an extensive computer bibliographic search. Databases such as Index Medicus, Biological Abstracts, SCISEARCH and Web of Science were used to acquire relevant information from studies.

A database was created containing the relevant information obtained from the review. Several criteria were established in order to determine if a reference (study) would be included in the database. References that generated data from hospital or clinical studies, were not included. For removal or inactivation assessment, only studies that used the glove juice methodology (i.e., human tests) as opposed to in vitro testing and having sufficient data to quantify the reduction ratio ($N/N_0$) were considered. Much of the information in the literature was not usable due to lack of results to quantify $N/N_0$ (e.g., only “non detects”) and incomplete description of the methodology used for the study.

Results and discussion

Microbial reduction

For the reduction of microorganisms on hands, surprisingly few data were found that met the criteria for inclusion in the study database. The studies selected,
germicidal active ingredients, and number of data points are summarized in Table 1. These studies had data on the removal of E. coli from hands using products at concentrations that could be found in consumer products.

A descriptive summary of the removal or inactivation data is presented in Fig. 1. Qualitatively, there is a difference in the degree of reduction exhibited by products with different active ingredients. This was confirmed by analysis of variance, and in particular the difference in reduction achieved by alcohol containing products was significantly different from the other products (including no active ingredient). Iodine-containing products were not considered further since they are not currently, nor are they expected to be used in the consumer market.

**Table 1. Summary of available data for E. coli removal from hands by products with various active ingredients**

<table>
<thead>
<tr>
<th>Active ingredient (abbreviation)</th>
<th>Data points</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alcohols (ALC)</td>
<td>13</td>
<td>Ayliffe et al. (1988), Rotter (1996)</td>
</tr>
<tr>
<td>Chlorhexidine/hibiclens (CHEX)</td>
<td>6</td>
<td>Ayliffe et al. (1988), Lee et al. (1988), Rotter (1996), Sheena and Stiles (1983)</td>
</tr>
<tr>
<td>Triclosan/hexachlorophene(TSAN)</td>
<td>5</td>
<td>Ayliffe et al. (1988), Rotter (1996), Sheena and Stiles (1983)</td>
</tr>
<tr>
<td>Iodine/povidone (Iodine)</td>
<td>6</td>
<td>Ayliffe et al. (1988), Reybrouck (1986), Sheena and Stiles (1983)</td>
</tr>
<tr>
<td>Parachlorometaxylenol (PCMX)</td>
<td>1</td>
<td>Sheena and Stiles (1983)</td>
</tr>
<tr>
<td>Non-germicidal (NONG)</td>
<td>4</td>
<td>Ayliffe et al. (1988), Sheena and Stiles (1983)</td>
</tr>
</tbody>
</table>

**Fig. 1.** Percentile plot of E. coli removal by products containing different active ingredients.

Distributional fitting

In addition to microbial removal or reduction, several other probability distributions were incorporated into this model. This model was constructed in Microsoft Excel® and used in conjunction with an add-in statistical software package, Crystal Ball®, which performs Monte Carlo analysis. Statistical distributions were fitted to the data using Crystal Ball®. The Kolmogorov-Smirnov test was used to determine which distribution best described the data. The selected best-fit distributions for each of the inputs are given in Table 2.

In the open literature, a transfer rate for E. coli from ground beef to hands could not be found. Due to this, the transfer rate model parameter was used from a Salmonella and chicken transfer study (Chen et al., 2001).

The non O157:H7 enteropathogenic E. coli occurrence data were taken from Russell (2000). The data were extracted from the article and the beta distribution was determined to provide the best representation of the data. The E. coli O157:H7 data were found in Tuttle et al. (1999).

**Infectivity**

The infectivity dose response curve of non-O157:H7 pathogenic E. coli was that presented in Haas et al. (2000). The relationship is beta-Poisson with a (best fit) median infective dose ($N_{50}$) of $8.610^7$, and a value of $\alpha$ of 0.18. To generate an uncertainty distribution for the dose-response, the underlying experimental data were bootstrapped to get a distribution for the dose-response parameters. This distribution (which was used as an input into the risk assessment) is shown in Fig. 2.

The dose-response relationship for E. coli O157:H7 was that previously reported based on a study on infant rabbits, and validated against human outbreak data (Haas et al., 2000). This also was a beta-Poisson relationship with best-fit values of $N_{50}$ and $\alpha$, of $5.96 \times 10^7$ and 0.49, respectively. The best-fit parameters and their bootstrap distribution are shown in Fig. 3. The more irregular shape of the O157:H7 bootstrap distribution (as compared to the non-O157:H7 distribution) is due to the underlying nature of the dose-response data, which are sparser and contain fewer points at low dose than the non-O157:H7 E. coli.

**Monte Carlo results**

Fig. 4 is a lognormal probability plot for the E. coli case study. Fig. 5 is a lognormal probability plot for the E. coli O157:H7 case study. It is clearly seen that there is
a higher probability of infection in the no hand-washing scenario when compared to the antibacterial hand washing scenario. The major difference between the two simulations is seen in the upper tails of the probability of infection plot. The 

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Distribution</th>
<th>Mean</th>
<th>Alpha</th>
<th>Scale</th>
<th>Loc.</th>
<th>Shape</th>
<th>Std. Dev.</th>
<th>Min</th>
<th>Max</th>
<th>Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Log₁₀ reduction using alcohol</td>
<td>Weibull</td>
<td>6.75</td>
<td>-2.10</td>
<td>7.94</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Log₁₀ reduction using chlorhexidine</td>
<td>Extreme value</td>
<td>0.45</td>
<td></td>
<td>3.16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Log₁₀ reduction using non-germicidal product</td>
<td>Gamma</td>
<td>1.29</td>
<td>1.22</td>
<td>0.41</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Log₁₀ reduction using triclosan</td>
<td>Uniform</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Log₁₀ MPN (#/g) of total E. coli MPN/g (E. coli O157:H7)</td>
<td>Beta</td>
<td>1.05</td>
<td>0.97</td>
<td>6.04</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Transfer rate</td>
<td>Log normal</td>
<td>15.81</td>
<td>48.40</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Transfer rate-SDA (ground beef-hand)</td>
<td>Weibull</td>
<td>0.45</td>
<td>3.16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Transfer rate (finger tips-mouth)</td>
<td>Log normal</td>
<td>1.29</td>
<td>1.22</td>
<td>0.41</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A formal sensitivity analysis was conducted as part of this study (data not shown). The most influential parameter in the E. coli simulations was the Log₁₀ MPN or MPN/g parameter. The log₁₀ reduction parameter was the most influential for the E. coli O157:H7 simulations. The effect of uncertainty in the dose-response parameters was small, although it was greater in the case of the O157:H7 risk assessment, due to the irregularity of the bootstrap distribution for the dose-response parameters.

Statistical summaries for the simulations are found in Table 3. The mean risks are much greater than the
median risks, due to the asymmetry in the various input distributions, and particularly for *E. coli* O157:H7 the irregular shape of the bootstrap distribution for the dose-response parameters (Fig. 3).

It should also be noted that these risks are conditional in the sense that they quantify the risk to an individual who has handled ground beef and who engages in hand to mouth activity (with the stipulated hand cleansing behavior). The probability that an individual who handles ground beef will engage in such behavior is not known, and therefore a direct comparison to actual disease rates cannot be made. However, with some plausible assumptions we may compare the outputs of this assessment to reported illness rates. Assuming that there are 100 million individuals (in the US) each of whom handles ground beef once per month—this results in $1.2 \times 10^9$ contacts per year. Assume 10% of these individuals contact hands to mouth after handling ground beef—$1.2 \times 10^8$ incidents per year. For *E. coli* O157:H7, using the median risk, this would result in an estimate ranging from 0.00005 (if all individuals used alcohol containing products between contact with ground beef and transference to the mouth) to 0.7 (if no hand washing is done) infections per year. This can be compared to a report of (in 1997) 2555 confirmed, reported cases of illness from *E. coli* O157:H7 from all sources (CDC (Centers for Disease Control and Prevention), 1998). Hence it would appear that the estimated risk from this route of exposure is relatively low, which is not unexpected (due to greater risks from direct ingestion of undercooked ground beef, undisinfected water, and person to person contact).

It is seen that there is a higher probability of infection in the no hand-washing scenario when compared to the antibacterial hand washing scenario. Additionally, washing hands with non-germicidal products also reduces the probability of infection. The reduction in risk is greater when using alcohol or chlorhexidine as the active ingredient compared to non-germicidal products. However, using non-germicidal products appears to be just as effective as using products that have triclosan as the active ingredient.

**Conclusions**

This work has demonstrated that a QMRA framework can be applied to the estimation of benefits from use of anti-microbial hand products. In the particular scenarios here, it is clear that the following emerge:

1. There is a reduction in risk from the use of any hand washing protocol as compared to no hand washing.
2. The amount of risk reduction obtained from the use of triclosan-containing products (as compared to handwashing using non-germicidal containing products) is smaller than that when products with alcohol or chlorhexidine as active ingredients are used.

This approach should be expanded examining other scenarios of use and other products.

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**Table 3. Risk of infection from handling contaminated ground beef and subsequent hand-to-mouth contact, with or without postcontamination hand treatment – Summary statistics for Monte Carlo simulations (6000 trials)**

<table>
<thead>
<tr>
<th>Active</th>
<th>Escherichia coli</th>
<th>Escherichia coli O157:H7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ALC</td>
<td>CHEX</td>
</tr>
<tr>
<td>Mean</td>
<td>5.46E−08</td>
<td>3.62E−07</td>
</tr>
<tr>
<td>Median</td>
<td>5.36E−12</td>
<td>1.21E−10</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>1.33E−06</td>
<td>6.25E−06</td>
</tr>
</tbody>
</table>

**Fig. 5.** Probability of infection for all scenarios (*E. coli* O157:H7 ground beef case study).
Acknowledgments

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References


