Marine Waters Contaminated with Domestic Sewage: Nonenteric Illnesses Associated with Bather Exposure in the United Kingdom

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ABSTRACT

Objectives. This study identified possible dose–response relationships among bathers exposed to marine waters contaminated with domestic sewage and subsequent risk of nonenteric illness.

Methods. Four intervention follow-up studies were conducted within the United Kingdom. Healthy volunteers (n = 1273) were randomized into bather and nonbather groups. Intensive water-quality monitoring was used to assign five bacteriological indices of water quality to individual bathers. Illnesses studied were acute febrile respiratory illness, and eye, ear, and skin ailments.

Results. Fecal streptococci exposure was predictive of acute febrile respiratory illness, while fecal coliform exposure was predictive of ear ailments. Estimated thresholds of effect occurred at bather exposures above 60 fecal streptococci and 100 fecal coliform per 100 ml of water, respectively. Although no relationship was found between eye ailments and indicator organism exposure, compared with nonbathers, bathers were at higher risk for eye ailments.

Conclusions. Nonenteric illness can be transmitted via recreational contact with marine waters contaminated with sewage. These results argue against the use of a single indicator to establish water quality standards. (Am J Public Health. 1996; 86:1228–1234)

Introduction

The possible transmission of infectious disease via contact with recreational waters contaminated with domestic sewage has been the subject of 11 previously published major prospective epidemiological studies.1–11 By far the most consistent finding has been an increased risk of gastroenteritis among bathers relative to nonbathers. To a lesser extent, previously published studies have reported bathers to be at excess risk of respiratory, ear, eye, and skin ailments, although the definition of each of these ailments and the associated risks have varied widely among studies.1,4,7–9,11

To date, gastroenteritis is the only single disease entity in which a mathematical model of a dose–response relationship between increased exposure to bacteriological indices of sewage pollution (indicator organisms) and subsequent risk of illness has been reported.3,12–14 Other studies have reported dose–response relationships between increasing exposure to indicator organisms and excess illness among bathers, but these studies had to combine two or more etiologically distinct illnesses in order to derive the relationships that they reported.3,9,11

Any mathematical model of a dose–response relationship that relates indicator organism exposure to a grouping of two or more unrelated infectious illnesses carries the assumption that all of the distinct underlying infectious agents causing the illnesses have the same relationship with the indicator organism used in the model or that all the disease entities included in the grouping are due to the same infectious agent. There is little biological evidence to support either of these assumptions. In addition, interpreting such models becomes problematic. This is because such models assume that the bather exposed to a particular indicator organism density is at equal risk of contracting each of the ailments that compose the grouping. Since the groupings used in previously reported mathematical models combined distinct conditions (e.g., eye or skin disorders) with other illnesses that may have different long-term outcomes and complications (e.g., gastroenteritis or respiratory illness in the very young or very old), the usefulness of such models becomes questionable.

We now report the results of four intervention follow-up studies we conducted to explore the relationship between bather exposure to increasing levels of domestic sewage pollution (as measured by indicator organism exposure) and subsequent risk of acute febrile respiratory illness and eye, ear, and skin ailments. Our findings regarding swimming-associated enteric illness have been published elsewhere.3,11
Methods

General

A detailed description of the study methods used in each of the four intervention follow-up studies has been published elsewhere.13 Briefly, four study locations located in the United Kingdom were used. The study locations were sufficiently distant from each other so that possible site-specific differences in the risk of bathing-associated illnesses could be assessed.13 All study locations met European Community mandatory bacteriological marine bathing-water quality criteria. Adult volunteers (> 18 years) were recruited in population centers close to specific study locations. There was no duplication of volunteer cohorts between study locations. Ethical clearance for all four studies was granted by the Royal College of Physician’s Committee for Research on Healthy Volunteers. Informed consent was obtained from all study volunteers in such a manner as to keep volunteers blinded to the non-teric outcome illnesses under study. Four separate studies were conducted in four successive bathing seasons during the summers of 1989 through 1992.

Healthy volunteers were randomized into bather and nonbather groups; the duration and place of individual bather exposure was rigorously controlled; indicator organism exposure was assigned to individual bathers within 15 minutes of actual exposure and within a maximum of 10 meters of the actual point of exposure; and each volunteer was given extensive pre- and post–trial-day interviews designed to identify, quantify, and control for non–water-related risk factors and/or possible confounders for the outcome illnesses under study. The interviews were as follows: initial interview 2 or 3 days prior to each trial, trial day interview, first follow-up interview at 7 days, and second follow-up at 3 weeks post–trial day). Study subjects did not know their exposure status (bather or nonbather) until they reported to the beach. Bathers were encouraged to spend at least 10 minutes in the water and were required to completely immerse their heads 3 times during exposure. No bathing caps or other protective gear was allowed. “Beach supervisors” recorded the duration of exposure of each bather. Nonbathers were kept in a roped-off area distant from the water, and “beach supervisors” ensured that no nonbather entered the water.

Water quality was sampled at 30-minute intervals for the following five bacteriological indices of water quality: total coliform, fecal coliform, fecal streptococci, total staphylococci, and Pseudomonas aeruginosa.14 Samples were collected in the surf zone, in waters approximately 1 m deep, and in waters approximately 1.3 m to 1.4 m deep (chest depth). At each of these three sampling locations, samples were taken 30 cm below the water’s surface. It should be noted that chest depth was the actual location of bather exposure.

Study Population

A total of 1528 study participants aged 18 or older completed the initial interview, of which a total of 1329 attended the beach. Of these, 56 either failed to comply with their randomization status (n = 23) or were lost to follow-up. This left a total of 1273 study participants, which constitutes an overall follow-up rate of 83.3% over the four intervention trials. An additional 57 bathers lacked indicator organism exposure data and were excluded from further analysis. Therefore, a total of 1216 participants (548 bathers and 668 nonbathers) were eligible for inclusion in subsequent analyses. When stratified by study location, the number of bathers and nonbathers constituting the study cohort were as follows: Langland Bay (1989), 120 bathers vs 133 nonbathers; Moreton (1990), 101 bathers vs 164 nonbathers; Southsea (1991), 172 bathers vs 186 nonbathers; and Southend on Sea (1992), 155 bathers vs 185 nonbathers. The mean age of the final bather cohort was 31.65 years vs 32.12 years for the final nonbather cohort. Fifty-four percent of bathers were male while 46.5% of nonbathers were male.

Outcome Illnesses or Ailments

Acute Febrile Respiratory Illness

Previously published epidemiological studies have failed to rigorously define respiratory symptoms according to some known classification of disease. To avoid this problem, we decided, prior to any statistical analysis, to classify respiratory illness as listed in the American Public Health Association’s Control of Communicable Diseases in Man.16 Therefore, the symptoms used in this report to define respiratory illness constitute the disease entity acute febrile respiratory illness (International Classification of Diseases [ICD], 9th revision, codes 461 through 466;480).16

The infectious agents suspected as being responsible for this disease are numerous viral agents. Among these viral agents are enteroviruses and adenoviruses that are discharged in the feces and that have been implicated in outbreaks of this illness among people bathing in swimming pools.18

Therefore, prior to any data analysis and in accordance with ICD criteria, volunteers were classified as having acute febrile respiratory illness if they experienced at least one of the symptoms listed in each of the following three categories: (1) fever; (2) headache and/or bodyaches and/or unusual fatigue and/or anorexia; (3) sore throat and/or runny nose and/or dry or productive cough. To help ensure that each symptom reported was part of a single illness, we counted only symptoms reported at a single follow-up interval (i.e., either at the 7-day follow-up interview or between 8 and 21 days after each trial date).

Ear, Eye, and Skin Ailments

The term “ear ailment” includes any reported incidence of ear pain, with or without accompanying discharge. The term “eye ailment” includes any reported incidence of sore, red eyes with or without concurrent discharge. The term “skin ailment” includes all cases of skin rash, skin ulcers and/or sores, and skin irritation accompanied by itching.

Statistical Analysis

Comparisons of Bathers and Nonbathers

The primary purpose of this study was to identify possible dose–response relationships among bathers exposed to varying levels of domestic sewage (as measured by indicator organism exposure) and subsequent risk of nonenteric illness and to identify possible thresholds of effect (indicator organism exposures at which bathers experienced no excess risk of contracting a nonenteric illness relative to nonbathers). Therefore, the nonbather cohort was used primarily to provide a baseline upon which to estimate thresholds of effect.

The success of randomization was assessed by comparing the distribution of non–water-related risk factors for the illnesses under study among bathers vs nonbathers. This was done by univariate chi-square analysis. If randomization was
TABLE 1—Acute Febrile Respiratory Illness among Nonbathers vs Bathers at Quartiles of Fecal Streptococci Exposure, the United Kingdom

<table>
<thead>
<tr>
<th>Exposure Status</th>
<th>No.</th>
<th>Rate/100</th>
<th>P (Trend)</th>
<th>P (Q4 Bathers vs Nonbathers)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonbathers</td>
<td>665</td>
<td>3.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bathers, by exposure&lt;sup&gt;2&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0–14</td>
<td>124</td>
<td>4.0</td>
<td>.043</td>
<td></td>
</tr>
<tr>
<td>15–27</td>
<td>138</td>
<td>5.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>28–50</td>
<td>126</td>
<td>1.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>51–158</td>
<td>158</td>
<td>7.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bathers only</td>
<td></td>
<td></td>
<td>.36</td>
<td></td>
</tr>
</tbody>
</table>

Note. Water quality samples were taken at chest depth. We assessed for the following non–water-related risk factors or possible confounders: age (by 10-yr intervals); gender; total no. people in household; illness in household 2 weeks prior to initial interview; flu-like symptoms among study participants within 4 weeks prior to initial interview; smoking; additional bathing within 3 days prior to 3 weeks after trial day; illness in household within 3 weeks subsequent to trial day; and respiratory illness among household members within 3 weeks subsequent to trial day that preceded illness in study participant.

<sup>2</sup>Comparison between bathers at highest quartile of fecal streptococci exposure vs nonbathers.

<sup>3</sup>Range of fecal streptococci densities (per 100 ml of sample) composing each quartile of exposure.

not successful for any non–water-related risk factor or possible confounders, multiple logistic regression was used to assess whether the effect of such failure confounded any differences in the risk of illness among nonbathers vs bathers. It should be noted that any additional exposure (bathing) within 3 days post–to 3 weeks post–trial day was identified for each study participant. Where a statistically significant difference was observed (P < .05) among the proportion of bathers vs nonbathers reporting such additional exposure, an appropriate term was entered into the multiple logistic model in order to control for possible confounding. A second multiple logistic regression analysis was also computed that excluded all bathers and nonbathers who reported additional bathing exposure. The results of this restricted analysis was then compared with the result of the unrestricted logistic regression analysis described above. In all instances, the restricted analyses yielded results that closely matched those derived from the unrestricted analyses.

Chi-square analysis was then used to identify any statistically significant trends among the observed incidence of a particular outcome illness among nonbathers vs bathers at quartiles of indicator organism exposure. Trend was assessed with the Mantel-Haenszel test for linear trend. A trend was considered statistically significant (P < .05) only if the chi-square for trend statistic remained statistically significant with and without the inclusion of the nonbather group. This ensures that differences between the reference group and the group with the lowest exposure do not unduly influence the chi-square for trend statistic.<sup>15–19</sup>

A second series of trend analyses compared rates of illness among nonbathers vs bathers at 20- or 50-unit intervals of increasing indicator organism exposure. The Mantel-Haenszel chi-square for trend was again used to assess statistically significant trends, while the Pearson chi-square was used to determine the grouping at which indicator organism exposure rates of illness became statistically significantly greater (P < .05) among bathers than among nonbathers. (Where expected cell size was less than 5.0, Fisher’s Exact Test was used in lieu of the Pearson chi-square.) Again, a trend was considered statistically significant only if the chi-square for trend statistic remained statistically significant with and without the nonbather reference group. These series of trend analyses were conducted for the data obtained for each of the five indicator organisms assayed for, at each of the three sampling depths used, and for each of the outcome illnesses. The analyses were intended to provide some insight into possible “thresholds of effect” to be further evaluated through the use of a series of multiple logistic regression models.

Where a statistically significant trend was observed only with the inclusion of the nonbather series, rates of illness among nonbathers were compared with rates of illness among bathers in each quartile of indicator organism exposure.

Analyses Restricted to Bathers Only

When the series of univariate chi-square analyses, as discussed above, identified an association between a particular outcome illness among nonbathers vs bathers at increased exposure to indicator organism densities, multiple logistic modeling was used to evaluate relationships between indicator organism exposure and illness while controlling for extraneous non–water-related risk factors or confounders among ill vs non-ill bathers. The non–water-related risk factors or confounders included in each logistic regression model were identified via prior chi-square analysis of the distribution of these factors among ill vs non-ill bathers.

Three different multiple logistic regression models were fitted to the data in order to further define possible thresholds of effect. The models are as follows:

(1) \[
\text{Ln odds of illness among bathers} = \beta \text{Log}_{10}(\text{IOE} + 1) + \alpha_1 X_1 + \ldots + \alpha_i X_i
\]

(2) \[
\text{Ln odds of illness among bathers} = \beta \text{Log}_{10}(\text{IOE} - \text{TH}) + \alpha_1 X_1 + \ldots + \alpha_i X_i
\]

(3) \[
\text{Ln odds of illness among bathers} = \beta \text{Log}_{10}(\text{IOE} + 1) + \beta \text{Log}_{10}(\text{IOE} - \text{TH}) + \alpha_1 X_1 + \ldots + \alpha_i X_i
\]

where

IOE = Indicator-organism exposure of the individual bather (per 100 ml of sample) modeled as a continuous variable.

TH = Postulated “threshold” indicator organism exposure derived from bather vs nonbather comparisons described earlier.

Xi = Non–water-related risk factors or possible confounders for the particular outcome illness.

Model 1 would therefore represent a situation in which there was no threshold of effect; Model 2 would imply a threshold of effect, and Model 3 would represent a situation that implies no threshold of effect but that allows for different slopes in the dose–response relationship to occur above and below the hypothesized “thresholds.” It should be noted that the postulated threshold term (IOE - TH) for
Models 2 and 3 above was coded as follows: zero for indicator organism exposures less than the postulated threshold value and Log10[(IOE + 1) − TH] for indicator organism exposures equal to or greater than the postulated threshold value.

To test which of the above three models was most appropriate for the data under analysis, we computed the log likelihood statistic9 for each model. We contrasted Models 1 and 2 with Model 3 using a hierarchical (backward elimination) strategy. In this manner, multiple logistic regression analysis was used to further test the validity of any “threshold of effect” found via previous univariate analysis of the bather versus nonbather cohorts.

It should be noted that a set of indicator variables was included in each logistic model to identify possible site-specific effects on the occurrence of the outcome illnesses under study, as well as a term that assessed the effect of duration of exposure. Again, we assessed the effect of additional unsupervised bathing from 3 days pre- to 3 weeks post–trial day via inclusion of an appropriate term in the logistic regression models and via repeating the logistic regression analyses described above restricted to bathers who reported no such additional bathing exposure. In all instances, the restricted analyses yielded results that closely matched those of the unrestricted analyses. A backward, stepwise elimination strategy was employed to identify and control for significant non–water-related risk factors or confounders in each logistic regression model.

Results

Acute Febrile Respiratory Illness

Twenty-seven of 548 bathers, and 20 of 668 nonbathers, met the criteria for having acute febrile respiratory illness. These numbers do not include 2 bathers and 3 nonbathers who were classified as having this illness on an actual trial day and were thus excluded from subsequent analyses. Analysis of trend among nonbathers vs bathers at quartiles of exposure and at 20-unit intervals of increasing indicator-organism exposure was carried out for each of the five indicator organisms assayed for at each of the three sampling depths used. Only fecal streptococci exposure derived from samples taken at chest depth showed any evidence of a statistically significant trend (range of exposure 0 through 158 fecal streptococci per 100 ml).

Table 1 shows rates of illness among nonbathers vs bathers at increasing quartiles of fecal streptococci exposure. A table showing rates of illness among nonbathers vs bathers at 20-unit intervals of increasing exposure is available from the authors.) Inspection of Table 1 shows a statistically significant trend across quartiles of fecal streptococci exposure when the nonbather group was included in the analysis (P = .04), but this trend lost statistical significance when the analysis was restricted to bathers (P = .36). When bather rates of illness in each quartile of

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**TABLE 2—Logistic Regression Analysis of the Three Postulated Models for Acute Febrile Respiratory Illness, Bathers Only**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Model 1: Log10 (FS + 1) OR 95% CI</th>
<th>Model 2: Log10 (FS − 59) OR 95% CI</th>
<th>Model 3: Log10 (FS + 1) + Log10 (FS − 59) OR 95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Log10 (FS + 1)(^c)</td>
<td>2.51 (0.79, 7.92)</td>
<td>. . .</td>
<td>1.21 (0.34, 4.40)</td>
</tr>
<tr>
<td>Log10 (FS − 59)(^b)</td>
<td>. . .</td>
<td>2.53 (1.26, 5.05)</td>
<td>2.30 (0.93, 5.73)</td>
</tr>
<tr>
<td>Gender(^d)</td>
<td>3.31 (1.35, 8.07)</td>
<td>3.39 (1.38, 8.33)</td>
<td>3.40 (1.38, 8.35)</td>
</tr>
<tr>
<td>Illness in household(^e)</td>
<td>2.63 (0.83, 8.35)</td>
<td>2.87 (0.90, 9.16)</td>
<td>2.84 (0.89, 9.09)</td>
</tr>
<tr>
<td>Age(^e)</td>
<td>0.73 (0.51, 1.05)</td>
<td>0.72 (0.50, 1.03)</td>
<td>0.72 (0.50, 1.03)</td>
</tr>
</tbody>
</table>

Note. OR = odds ratio; CI = confidence interval.
\(^a\)Log10 term results in maximum fecal streptococci density of zero for fecal streptococci exposure less than 59 or log10 [fecal streptococci exposure + 1] − 59 for fecal streptococci exposure greater than or equal to 59. FS = fecal streptococci density per 100 ml of sample.
\(^b\)Reference group = males.
\(^c\)Includes illness in household occurring within 3 weeks after the study day with or without information regarding whether illness preceded reported illness among individual study participants (bathers).
\(^d\)Modeled continuously in intervals of 10 years.

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**TABLE 3—Ear Ailments among Nonbathers vs Bathers at Quartiles of Fecal Coliform Exposure, the United Kingdom**

<table>
<thead>
<tr>
<th>Exposure Status(^)</th>
<th>No.</th>
<th>Rate/100</th>
<th>P (Trend)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonbathers</td>
<td>636</td>
<td>2.8</td>
<td></td>
</tr>
<tr>
<td>Bathers, by exposure</td>
<td></td>
<td></td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>0–40</td>
<td>120</td>
<td>6.7</td>
<td></td>
</tr>
<tr>
<td>41–79</td>
<td>113</td>
<td>6.2</td>
<td></td>
</tr>
<tr>
<td>80–133</td>
<td>152</td>
<td>5.9</td>
<td></td>
</tr>
<tr>
<td>134–661</td>
<td>134</td>
<td>14.2</td>
<td></td>
</tr>
<tr>
<td>Bathers only</td>
<td>. . .</td>
<td>. . .</td>
<td>.042(^d)</td>
</tr>
</tbody>
</table>

Note. Water quality samples were taken at chest depth. We assessed for the following non–water-related risk factors or possible confounders: age; gender; illness in household within 2 weeks prior to initial interview; history of ear problems; ear infection within 4 weeks prior to initial interview; additional bathing within 3 days prior to 3 weeks after trial day; illness in household within 3 weeks subsequent to trial day; and ear ailments among household members within 3 weeks subsequent to trial day that preceded illness in study participant.
\(^a\)Analysis excludes six bathers missing fecal coliform exposure data.
\(^b\)Range of fecal coliform densities (per 100 ml of sample) composing each quartile of exposure.
\(^c\)Comparison among bather groupings only.
exposure were compared with the rates of illness among nonbathers, only those bathers exposed to the highest quartile of exposure (51 through 158 fecal streptococci per 100 ml of sample) showed a statistically significant increase in the risk of acquiring acute febrile respiratory illness relative to nonbathers (odds ratio OR = 2.65; 95% confidence interval CI = 1.19, 5.48, P = .007). Similarly, comparison of illness rates among nonbathers vs bathers at 20-unit intervals of fecal streptococci exposure showed that excess risk of illness among bathers relative to nonbathers did not occur until exposure to approximately 60 or more fecal streptococci organisms (OR = 3.92; 95% CI = 1.59, 9.49, P = .0014).

None of the applicable non-water-related risk factors or possible confounders (see note to Table 1) conferred the observed difference in illness rates among nonbathers vs bathers exposed to increasing fecal streptococci exposure, as shown in Table 1.

We then used multiple logistic regression analysis to evaluate any dose–response relationship between illness among bathers vs exposure to increasing fecal streptococci density while controlling for possible confounding by the non-water-related risk factors. Since the univariate analysis provided evidence that bather rates of illness did not exceed those of nonbathers until exposure to 60 or more fecal streptococci, three separate multiple logistic regression models were evaluated: (1) a “no-threshold” model, (2) a model that assumes a threshold of effect at exposure to 60 or more fecal streptococci, and (3) a model that allows for different dose–response relationships above and below the theorized “threshold value” (60 fecal streptococci per 100 ml).

Table 2 shows the results of these analyses. The goodness of fit of each of the three models shown in Table 2 was assessed with the log likelihood statistic. These analyses yielded the following results: There is a nearly statistically significant decrease in the goodness of the fit of the model (P = .08) when the “threshold” term \( \log_{10}(\text{FS} - 59) \) is removed from the model containing both the \( \log_{10}(\text{FS} + 1) \) and \( \log_{10}(\text{FS} - 59) \) terms (Model 3). In contrast, removal of the “nonthreshold” term \( \log_{10}(\text{FS} + 1) \) from Model 3 clearly did not decrease the fit of the model (P = .75). This suggests that the model containing only the \( \log_{10}(\text{FS} - 59) \) term (Model 2, Table 2) is the most appropriate logistic regression model for the data under analysis.

Inspection of Model 2 in Table 2 shows a statistically significant dose–response relationship between fecal streptococci exposure and the occurrence of acute febrile respiratory illness among bathers. The logistic model showed no indication of any site-specific effects on outcome, no effect of duration of exposure on outcome (mean duration of exposure among ill vs non-ill bathers was 13.0 min vs 14.6 min, respectively; P = .26), and no statistically significant interaction between fecal streptococci exposure and the other independent variables in the model (gender, illness in household, or age). Lack of such interaction makes all factors listed in Model 2, Table 2 independent predictors of acute febrile respiratory illness.

**Ear Ailments**

Out of a total of 548 bathers and 668 nonbathers eligible for inclusion in this analysis, 23 bathers and 32 nonbathers were excluded from further analysis because of reported ear ailments within 3 days of the trial day. Of 525 bathers, 43 met the criteria for having an ear ailment postexposure, as did 18 of 636 nonbathers. Again, bathers were initially divided into quartiles of indicator organism exposure, and separate analyses were conducted for each indicator organism assayed for and at each of the three water-quality sampling depths used. Only fecal coliform organisms derived from samples taken at chest depth showed statistically significant trends in the incidence of ear ailments with increasing quartiles of fecal coliform exposure, with and without inclusion of the nonbather group (Table 3).

Since the range of fecal coliform levels varied from 0 through 661 organisms per 100 ml of sample among estimates derived from samples taken at chest depth, we decided to group bather exposure by units of 50 fecal coliform organisms to further refine any dose–response relationship with respect to a possible “threshold” of effect. This analysis also showed a statistically significant increasing trend in the incidence of ear ailments vs increasing fecal coliform exposure among bathers, with and without the inclusion of the nonbather group (data available from the authors). Both trend analyses showed clear evidence that increased risk of ear infection did not increase significantly (P < .05) until bather exposure to approximately 100 or more fecal coliform organisms. None of the factors listed in the note to Table 3 were found to confound the observed difference in the rates of ear infection among nonbathers vs bathers at increasing quartiles of 50-unit intervals of fecal coliform exposure, as shown in Table 3.
We then used multiple logistic regression analysis to evaluate dose–response relationships between ear ailments among bathers at exposure to increasing levels of fecal coliform while controlling for possible confounding by non–water-related risk factors. Again, three separate logistic regression models were evaluated: (1) a “no-threshold” model, (2) a model that assumes a threshold of effect at exposure to 100 or more fecal coliform, and (3) a model that allows for different dose–response relationships above and below the theorized “threshold value” (100 fecal coliform per 100 ml).

To assess for possible site-specific effects on the distribution of ear ailments among bathers, we entered a set of indicator variables into each of the above regression models, as well as a term that assessed the effect of duration of exposure. We found no site-specific effects and no statistically significant interaction between the effect of fecal coliform exposure and the other main effects. Mean duration of exposure among ill vs non-ill bathers was 13.8 min vs 14.4 min, respectively (P = .52).

We assessed the goodness of fit for each of the three models (Table 4) using the log likelihood statistic. These analyses yielded the following results: when the “threshold” term Log_{10}(FC – 100) was removed from the model containing both the Log_{10}(FC + 1) and Log_{10}(FC – 100) terms (Model 3, Table 4), there was a nearly statistically significant decrease in the goodness of the fit of the model (P = .058). Removal of the “nonthreshold” term Log_{10}(FC + 1) from Model 3 of Table 4 did not decrease the model’s goodness of fit (P = .84). These results suggest that the model containing the threshold term Log_{10}(FC – 100) (Model 2, Table 4) is the appropriate logistic regression model for the data under analysis.

Inspection of Model 2, Table 4, shows a statistically significant dose–response relationship between fecal coliform exposure and the occurrence of ear ailments among bathers. It must be stressed that no interaction was observed between any of the independent variables shown in Model 2, Table 4.

**Eye Ailments**

Ten bathers and 10 nonbathers reported having an eye ailment on one of the four trial days and were excluded from further analyses. When bathers were divided into quartiles of indicator organism exposure, there was no evidence of a trend in increased risk of eye ailments among nonbathers vs bathers at quartiles of increasing indicator organism exposure. This was true for each of the five indicator organisms assayed at each of the three water-quality sampling depths used. Bathers exposed to the highest quartiles of indicator organism exposure were then compared with nonbathers and bathers exposed to the lowest quartile of indicator organism exposure. No statistically significant differences in reported rates of eye ailments were observed for any of the indicator organisms assayed at any of the three sampling depths used. Higher rates of eye ailments among bathers relative to nonbathers were, however, observed at all four study locations. When the data from all four study locations were combined, bathers were observed to have statistically significantly higher rates of eye ailments than nonbathers (Mantel-Haenszel weighted odds ratio = 2.06; 95% CI = 1.01, 4.25).

No confounding of the observed excess risk among bathers was found to occur with respect to any of the non–water-related risk factors or possible confounders, nor was there any difference in the average duration of exposure among bathers who reported eye ailments and those who did not (12.8 min vs 14.5 min, respectively; P = .23). Again, no site-specific effects on the distribution of eye ailments were observed.

**Skin Ailments**

Seventy-nine bathers and 93 nonbathers were excluded from subsequent analysis because they reported a history of chronic skin ailments, specifically eczema or psoriasis, or reported a skin ailment on the trial day. Comparisons were made of the rates of skin ailments among nonbathers vs bathers at quartiles of indicator organism exposure. No statistically significant trends in skin ailment rates were observed for any of the five indicator organisms assayed at any of the three sampling depths used. In addition, we observed no statistically significant differences when comparing bathers exposed to the highest quartiles of indicator organism densities with nonbathers or bathers exposed to the lowest quartile of indicator organism densities. This was true for all indicator organisms assayed at each of the
Discussion
The results reported herein show a clear dose–response relationship between bather exposure to increasing levels of fecal streptococci and increased risk of acquiring acute febrile respiratory illness; exposure to increased levels of fecal coliform organisms was found to be predictive of ear ailments among bathers. These findings provide evidence of possible underlying pathogen-specific relationships among different indicator organisms, and thus the ability to predict different illnesses associated with recreational swimming. Moreover, “thresholds” of indicator organism exposure below which bathers were at no excess risk of illness relative to nonbathers were estimated to be 60 fecal streptococci for acute febrile respiratory illness and 100 fecal coliform for ear ailments (Figures 1 and 2). These findings argue against the use of a single illness or indicator organism in the establishment of marine standards for recreational swimming.

This is the first epidemiological study to report a dose–response relationship between increasing fecal streptococci exposure and the risk of acquiring acute febrile respiratory illness. Unlike other illnesses or ailments found to be associated with bathing in marine waters contaminated with domestic sewage (i.e., ear or eye ailments), the rubric of acute febrile respiratory illness includes lower respiratory tract illnesses, which are potentially serious illnesses, particularly in the very young and very old. However, we observed no lower respiratory tract illnesses among our study participants.

Care must be used in the interpretation of the thresholds of risk we report. Given the strengths inherent in the study design used, relative to other published epidemiological studies, these thresholds are probably the most accurate estimates derived to date. The possibility does exist, however, that our study design lacked sufficient power to detect increased risk of illness among bathers exposed to indicator organism densities below the thresholds we report.

With respect to the sampling depth most appropriate to use in conducting future epidemiological studies or in the routine sampling of marine bathing waters, this report showed that when a dose–response relationship was found between increasing indicator organism exposure and illness among bathers, the relationship held only for estimates of indicator organism density derived from samples taken at or near the point of actual head immersion (chest depth). It must, however, be emphasized that the bather cohort in our study consisted of adults 18 years of age or older. This finding must therefore be interpreted with care, especially with respect to small children who would tend to be exposed to waters of less depth. It is thus quite possible that indicator organism densities derived from samples taken within the surf or at a depth of 30 cm would be more appropriate for assessing risk among small children.

The reliance on volunteers to compose our study cohorts can generate criticism with respect to the generalizability of study results beyond the study cohort. This use of volunteers should have little effect on the generalizability of the results to the entire adult population at risk. It is probable that the individuals who volunteered for the study are people who enjoy bathing and are thus representative of the target population, which, in this case, is people 18 years of age or older who bathe in coastal waters.

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