ABSTRACT

There is a measurable risk of acute gastroenteritis associated with swimming in marine waters contaminated with human fecal wastes to levels that would be aesthetically acceptable. The enterococcus level in the bathing water is the best single measure of its quality relative to the risk of swimming-associated, pollution-related infectious disease. Three mathematically expressable indicator-illness relationships (criteria) are available from which recreational water quality guidelines can be extrapolated from the criteria once a decision has been made as to the acceptable risk of illness. The recently revised USEPA recreational water quality criteria and guidelines reflect this regulatory approach. A model is presented for the regulation of water quality which defines decision-making and actions by federal and local agencies as well as resource users. This model requires the ability to predict illness rates from monitoring data. Three equations, each corresponding to one of the criteria, are available for doing so. Concept and supporting epidemiological data indicate that the criteria do not apply to situations in which the sources of contamination are the fecal wastes from small numbers of individuals (e.g. boat wastes, the bathers themselves) or from lower animals (e.g. stormwater run-off). Differential die-off of viral pathogens and the bacterial indicator during wastewater chlorination and protracted residence in marine waters may also confound the use of the criteria in specific situations.

KEYWORDS

Recreational water quality; waterborne disease; water pollution; acute gastro-enteritis; enterococci; Norwalk virus; criteria and standards.

INTRODUCTION

Four related questions will be addressed in this review of swimming-associated, pollution-related infectious disease. They are: (i) Is there a measurable and significant risk of infectious disease associated with swimming in marine waters which are fecally contaminated to levels less than those which would be aesthetically unacceptable? (ii) If so, to which, if any, of these diseases is the risk great enough so that water quality criteria, guidelines and/or standards can be developed for limiting the risk to an acceptable level? (iii) Which measure of the quality of the bathing water best indexes the risk of illness and can serve as the basis for recreational water quality criteria? (iv) How may the risk of illness be predicted from monitoring data?
General Considerations

This review will concern itself only with infectious diseases which are both swimming-associated and pollution-related. As used herein, swimming includes other direct contact water activities, such as surfing and skin diving, in which there is a high probability of ingestion of the water. The requirement for a predictable relationship to pollution is pragmatic in that, in its absence, the information cannot be used as the basis for water quality guidelines and standards or pollution abatement. For example, almost all the prospective epidemiological studies conducted to date have shown that there is an increased rate of symptomatology, notably of general and respiratory complaints, associated with swimming per se. That is, even in relatively unpolluted waters, the symptom rates for swimmers were frequently higher, although not significantly so in most cases, than those for nonswimmers. There are a number of possible explanations, including a small or, under certain conditions, not so small probability of the transmission of infectious agents from one bather to another.

Sources of information. There are three sources of information concerning swimming-associated illnesses. They are reports of common source outbreaks as given to public health authorities and/or presented in the literature, case-control analyses of individual cases of illness, and the results of prospective epidemiological studies. A major difficulty with the use of case or outbreaks reports is that data on the quality of the bathing water at the time of the exposure are frequently unavailable. Because of this and the insensitivity of passive reporting systems for obtaining information on the rates of swimming-associated illness, the results from prospective epidemiologic investigations have been much more useful in the development of recreational water quality criteria, guidelines, and standards.

Potential causative (etiologic) agents. As seen from the presence of their etiologic agents in wastewater discharges, there are a large number of infectious diseases which could result from swimming in sewage-contaminated waters. The range of illnesses is much more restricted when documented outbreak reports are considered. Included are about six relatively small outbreaks of typhoid fever, the latest of which occurred in 1958 in Australia (Flynn and Thistlewayte, 1964). There have been a few very small outbreaks of shigellosis and one each due to the Coxsackie A (Denis et al., 1974), Coxsackie B (Hawley et al., 1973), and hepatitis A viruses (Bryan et al., 1974). All of these were associated with fresh bodies of water. The two reported major outbreaks of swimming-associated infectious disease were also from fresh water exposures, one of shigellosis (Rosenberg et al., 1976) and one of Norwalk virus gastroenteritis (Koopman et al., 1982). There have been no reported outbreaks of poliomyelitis associated with swimming, and this observation is consistent with the findings from the case-control study conducted by Moore and his associates in the 1950s (Moore, 1959). Moreover, the most prevalent sewage-related illness by the other two waterborne routes of transmission, consumption of raw molluscan shellfish and drinking water, is an acute gastroenteritis (Cabelli, 1983); and, of the outbreaks of this illness studied by serologic epidemiology in the U.S., about half were due to the Norwalk virus (Kaplan et al., 1982; Centers for Disease Control, 1987).

There have been some cases of infectious disease in which wounds incurred in the course of aquatic activities have become infected with members of the genera eromonas and Vibrio. Although these have frequently been serious in nature, the number of such cases as reported is small relative to the number of bathers. Undoubtedly, the requirement for a predisposing condition has contributed to this. External ear infections caused by Pseudomonas aeruginosa, however, are a relatively common swimming-associated illness, at least in fresh bodies of water. All three of these agents are autochthonous to marine or fresh waters; and, because of this, the risk of the illnesses caused by them is not particularly amenable to the development of pollution-based water quality criteria. Two of the agents, P. aeruginosa and Aeromonas, are found at high levels in municipal wastewater effluents (Miescier and Cabelli, 1982; Rippey and Cabelli, 1979) where they presumably multiply since they are found infrequently and at low levels in human fecal wastes. This notwithstanding, the results from most of the prospective...
epidemiologic studies conducted to date show that the swimming-associated, pollution-related areas for gastrointestinal symptoms are markedly higher than those for ear or skin complaints.

Potential sources of the agents. Pathogenic microorganisms found in human or lower animal fecal wastes may reach marine bathing waters directly or indirectly from six sources. They are (i) municipal wastewater and sewage sludge discharges, (ii) overflowing septic disposal systems for individual homes or buildings, (iii) the bathers themselves, especially in situations where there is high bather density and poor water exchange, (iv) sanitary wastes from small boats, (v) stormwater run-off, whether sewered or unsewered, and (vi) direct discharges from lower animals, notably waterfowl. For the reasons to be given, recreational water quality criteria, guidelines and standards based on fecal indicators apply only to beaches impacted by the first of these sources.

Water quality indicators. Space does not permit a discussion of all the recreational water quality indicators which have been considered, and the author has reviewed this subject in an earlier publication (Cabelli, 1982). One recurring question, however, is why not base the microbial water quality standards on the levels of the pathogens themselves in the bathing waters. Historically, fecal indicators were used in lieu of the pathogenic agents because of methodological problems; and this is true today with regard to the most important agents, the hepatitis A and Norwalk viruses. An equally, if not more, compelling reason is that the levels of the pathogens themselves in the bathing water have no predictability. Their levels in the water on a given day may have no predictability. Their levels in the water on a given day may have no relation to those found a month or even a week later. The one exception could be the viral agents of acute gastroenteritis because of their presumed ubiquity in sewage as seen from epidemiological studies.

RISK OF SWIMMING-ASSOCIATED ILLNESS

The first prospective epidemiological studies on swimming-associated illness were conducted by the United States Public Health Service in the early 1950s (Stevenson, 1953). The findings from these studies and problems in their design were reviewed in earlier papers by the author and his associates (Cabelli, 1978). The results obtained when symptom rates in individuals bathing in sewage-contaminated waters in a stretch of the Ohio River (total coliform level about 2000/100 ml) were compared to those among bathers using a nearby well-chlorinated swimming pool are particularly relevant to this review. The rate for all symptoms was significantly higher for bathing in the river, while that for gastrointestinal symptoms among children was significantly higher for bathing in the river.

Five additional prospective or follow-up type epidemiological studies were conducted at marine bathing beaches, and an additional two at fresh water beaches since the period from 1972-1981 when the United States Environmental Protection Agency conducted its marine and fresh water studies (Cabelli, 1980; Cabelli et al., 1982; Dufour, 1984) (Table 1). The marine studies were conducted in Egypt (Cabelli, 1980), England (Brown et al., 1987), France (Foulon et al., 1983), Israel (Fattal et al., 1986) and Spain (Mujeriego et al., 1982). The fresh water studies were conducted in Canada (Seyfried et al., 1985a, 1985b) and Connecticut, U.S.A. (personal communication, Calderon and Dufour).

The U.S. and Egyptian studies were the most extensive in the terms of the number of useful follow-up interviews, the number of years over which studies were conducted, and the number of beaches examined. Because of this, recreational water quality criteria and equations predicting illness rates from water quality measurements could be developed from these studies. In addition, there were two populations in the Egyptian studies, Alexandria residents and tourists from Cairo.

At least four subpopulations were examined in most of the studies, swimmers and beach-going nonswimmers (nonbathers or bathers who did not immerse their heads in the water) at a "more polluted" and a "less polluted" beach. The
more polluted beach(es) in the U.S., Israeli, French and English studies were not considered aesthetically unacceptable. Slightly less than half the individuals queried perceived the more polluted beach in the English study as being "very dirty", although not necessarily from fecal wastes. The qualities of the waters at the more polluted beaches in the English and French studies were within the European Economic Community mandatory guidelines (Council of European Communities, 1975), and those for the beaches in the U.S. and Israeli studies did not exceed the former USEPA 1986 guideline. The most polluted beaches in the Egyptian study were aesthetically unacceptable, at least to the author of this review, and the enterococcus and coliform levels exceeded the EEC standards and both U.S. guidelines. There are no data for one of the most important study population-bathing beach combinations, tourists from a country where environmental sanitation is well-developed swimming at beaches receiving the fecal wastes from populations where environmental sanitation is less developed.

### TABLE 1

Summary of Prospective Bathing Beach Epidemiological Studies

| Water | Country | Partic (x10³) | Loc | Beach | Stdy | Other | Symptomatology | Output from epidemiological program<br> | Age | 'Best'<br>| Indicator<sup>c</sup> |
|-------|---------|---------------|-----|-------|------|-------|----------------|----------------|-----|----------------------|
| Marine | USA | 26.7 | 3 | 9 | 13 | F,W | R,S,E | G | C | Ent. |<sup>e</sup> |
| Egypt | 23.2 | 1 | 4 | 9 | F,W | R,S,I | G | C | Ent., E. coli |<sup>e</sup> |
| Spain | 20.2 | 2 | 24 | 24 | S,E,I | G | | | | |
| France | 4.9 | 1 | 5 | 3 | F | R,S,E,I | G | | | |
| Israel | 1.6 | 1 | 2 | 2 | F,W | G | | | | |
| England | 1.9 | 2 | 2 | 2 | S,E,I | G | | | | |
| Fresh | USA | 45.9 | 2 | 4 | 9 | F,W | R,O | G | C | Ent., E. coli |<sup>e</sup> |
| Canada | 7.3 | 1 | 10 | 10 | S,E,I | (Ill,S,I)<sup>d</sup> | C | S. aureus |<sup>e</sup> |
| CT, USA | 0.16 | 1 | 1 | 1 | L,W | (G)<sup>d</sup> | C | S. aureus |<sup>e</sup> |

<sup>a</sup> - Partic - number of usable responses in thousands; Loc - number of locations; Beach - number of beaches; Stdy - number of studies (study = one beach for one summer); F - follow-up questionnaire used; W - water quality measured during study days, and individuals who swam on the 3-5 days before and after study day excluded; L - longitudinal study (49 days).

<sup>b</sup> - S-A - swimming-associated; S-A, P-R - swimming-associated, pollution-related; R - respiratory; S - skin; E - ear, I - eye; Ill - illness; O - symptoms other than respiratory or gastrointestinal; G - gastrointestinal; C - illness rates higher among children than adults.

<sup>c</sup> - Indicator whose levels in water correlate the best with S-A, P-R illness rates; Ent. - enterococci.

<sup>d</sup> - Source of pollution shown or suspected to be associated with bathers themselves.

The most prevalent swimming-associated, pollution-related symptomatology in both the marine and freshwater studies in the U.S., as well as the studies conducted in Egypt, France, Israel and England, was gastrointestinal. In most of these studies the rates for one or more of the gastrointestinal symptoms as obtained from follow-up questionnaires were significantly higher among swimmers than nonswimmers at the more polluted beaches. Moreover, in the U.S. and Egyptian studies, the data base was large enough to show that this was true of a clinical entity, acute gastroenteritis and that the rates were higher for children than adults (this also was true of the study conducted in Israel). Skin, ear, eye and/or respiratory symptoms also were appreciably or significantly higher among swimmers than nonswimmers in the studies conducted in Canada, Connecticut (USA), Spain and Israel. We speculate that this may have been due in part, at least, to contamination from
Swimming-associated illness

the bathers themselves under conditions of heavy usage and poor water exchange. Thus, we conclude that there is a measurable and significant risk of acute gastroenteritis associated with swimming in marine waters which are contaminated with human fecal wastes to levels less than those which would be aesthetically unacceptable.

THE BEST WATER QUALITY INDICATOR

As yet, there is no perfect recreational water quality indicator. Ideally, the levels of the indicator in the bathing water should correlate extremely well with the risk of swimming-associated, pollution-related acute gastroenteritis even in situations where there are lower animal but no human fecal inputs and when there is a nearby chlorinated wastewater discharge. That is, it should be human fecal specific and mimic the Norwalk virus in its survival during wastewater treatment and chlorination and transport in the water between source and target, at least during the swimming season.

Significant differences in the swimming-associated rates for gastrointestinal symptoms were obtained in the British and French studies where the total or fecal (thermotolerant) coliform levels were markedly different at the test and control beaches. However, when the levels of various indicators in the water were compared by regression analysis to the swimming-associated rates of acute gastroenteritis in the U.S. studies, there was poor correlation with these indicators and with staphlococci, Pseudomonas aeruginosa, aeromonads, and Clostridium perfringens. In the U.S. studies conducted at marine beaches, the enterococcus levels in the water correlated the best with enteric disease; and, in the fresh water studies, enterococci and E. coli were equally good in this regard.

Staphylococcus aureus levels appeared to correlate well with swimming-associated illness in situations where we suspect contamination from the bathers themselves may have contributed appreciably to both illness among the bathers and the S. aureus levels in the water (Table 1). If the indication (the Israeli and Connecticut studies) or supposition (the Canadian study) about the sources of contamination are correct, it would appear that S. aureus is a good indicator of illness due to cross-infection among bathers.

Contamination of the bathing water with the fecal wastes from the bathers themselves would carry the potential for swimming-associated disease due to human-specific viral agents. However, because of the small numbers of individuals who contribute to these sources, the predictability of illness based on fecal indicator levels in the water is expected to be poor. This also would be true of fecal discharges from overflowing septic systems and from pleasure-craft which contain sanitary facilities.

When the viral etiology of acute gastroenteritis is considered, the expectation is that contamination of the bathing water with lower animal fecal wastes would carry a much lower risk of illness than that from humans. All the fecal indicators currently used to assess water quality are found in both human and lower animal feces. Thus, to the extent that the bathing water is contaminated with stormwater which has no human fecal input or with direct animal discharges, the risk of illness predicted from coliforms (total coliforms, thermotolerant coliforms, or E. coli) or fecal streptococci (including enterococci) is probably overstated. In the Connecticut study, there were no sources of human fecal wastes except those from the bathers themselves. The fecal indicator levels were poorly, if at all, correlated to the rates of swimming-associated illness even though the enterococcus and coliform levels in the water were high (Calderon and Dufour, personal communication).

Although the enterococci better simulate the survival of some viruses in marine waters than do the coliforms (Fattal et al., 1983), the Norwalk virus is especially resistant to the viricidal effect of combined chlorine. Of the viruses studied by Keswick et al., (1985), only the F male-specific bacteriophages (F-2) were similar to the Norwalk virus in this regard. The F male-specific bacteriophages are much more resistant to wastewater chlorination and survive die-off in marine waters better than do the coliforms.
or enterococci (data to be published from our laboratory). Thus, we speculate that, in situations where a beach is near an outfall whose effluent has to be chlorinated to meet the existing bacterial guidelines, the risk of acute gastroenteritis will be underestimated by the enterococcus or coliform levels in the water. The above notwithstanding, for the present, at least, the enterococcus level in the bathing water is the best single measure of its quality relative to the risk of infectious disease. Monitoring data must be collected and used judiciously, however, since, as noted above, with certain sources of the indicator, the risk of illness may be overestimated; with others, it may be underestimated; and with still others, it may not be predicted with any certainty by any of the currently available fecal indicator systems.

RECREATIONAL WATER QUALITY CRITERIA

A recreational water quality criterion is defined as a mathematically expressable relationship from which some measure of the quality of the bathing water (guideline) can be extrapolated from an acceptable rate of swimming-associated illness. At this time, there are three criteria for marine and one for fresh recreational waters which relate the enterococcus levels in the water to the rates of swimming-associated acute gastroenteritis. The regression equations for the criteria for marine waters are given in Table 2. One derives from the U.S. studies, and two were obtained from the Egyptian studies, the first for Alexandria residents and the second for Cairo tourists at the Alexandria beaches. It can be seen from Table 2 that, for a given acceptable illness rate, the corresponding enterococcus level in the water would be the highest with the criterion developed from the data for the Alexandria residents, and the lowest with the one developed from the U.S. studies. Differences among the three study populations with regard to their immunity to the etiologic agent(s) best explain the differences.

<table>
<thead>
<tr>
<th>TABLE 2</th>
<th>Recreational Water Quality Criteriaa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>U.S. visitors</td>
</tr>
<tr>
<td>Slope</td>
<td>0.0456</td>
</tr>
<tr>
<td>Intercept</td>
<td>0.677</td>
</tr>
<tr>
<td>r</td>
<td>0.75</td>
</tr>
<tr>
<td>X, if Y = 19/1000b</td>
<td>0.35</td>
</tr>
</tbody>
</table>

a See Cabelli (1980) for data base; X on Y equation predicts log<sub>10</sub> enterococcus level/100 ml in the bathing water (X) for some acceptable illness rate/1000 swimmers (Y).

b Nineteen cases/1000 persons was the rate accepted by the USEPA (1986); used only as an example.

The use of these criteria in other parts of the world requires two decisions: which criterion, if any, is appropriate and what illness rate is acceptable. The U.S. criterion would produce the most stringent guideline, although we speculate that one developed for the tourists noted earlier would be even more restrictive. There is an urgent need for such a criterion.

The USEPA recently adopted the criterion developed from the U.S. studies, accepted a risk of the relatively benign illness, acute gastroenteritis, at the federal level of concern of about 19 cases/1000 swimmers, and recommended the corresponding guideline, a mean enterococcus level in the bathing water of 35 CFU/100 ml. It was assumed that, except under very unusual circumstances, the corresponding risk of more serious illness would be negligible. Thus the risk of swimming-associated acute gastroenteritis as indexed by the enterococcus levels in the water not only can be but is being used as the basis for water quality criteria and guidelines.
PREDICTING THE RISK OF SWIMMING-ASSOCIATED ILLNESS

Four general approaches or combinations thereof can be or have been used in regulating recreational water quality. The first is the absence of any intervention by regulatory agencies. It probably derives from the assumption that there will be no measurable or appreciable risk of swimming-associated, pollution-related illness unless the beaches are aesthetically unacceptable. It is clear from the results of the prospective epidemiological studies, that this approach is unrealistic. The second approach is to develop standards based on attainability. Its corollary is that the risk of swimming-associated illness was acceptable at the time the standards were promulgated but that any subsequent degradation in water quality would not be tolerated. The third approach requires the regulatory agency to publish summaries of the qualities of the water, and/or the predicted swimming-associated illness rates, for the beach for decision-making by the user. This is done by a number of agencies at the national and local levels. For example, the City of New York publishes an annual report containing microbiological data on the quality of those beaches which they approve for swimming. The fourth approach is the one now used in the United States. It is the development of criteria and guidelines as defined earlier at the national level. The guideline, expressed as a limit on the enterococcus level in the bathing water and the corresponding risk of swimming-associated illness that was accepted, is not very restrictive by design. It is the limit beyond which concern could be expressed at the federal level. The expectation was that local officials would want smaller risks of illness and, hence, would promulgate more restrictive standards.

A rather interesting regulatory mode appears to be emerging in the U.S. from a combination of the last two approaches. It consists of a national guideline which, if exceeded, would be the basis for intervention by federal officials to assure that corrective action is taken by local officials, either by pollution abatement or prohibition of the use of the resource. The second component is a state or local standard which, if exceeded, would require that a beach be posted as unsafe for swimming. The third component is the publication by local or state regulatory agencies of annual summaries of the water quality and/or the risk of swimming-associated illness for each beach within their jurisdictions. The user could then decide, within the framework of the decisions by federal and local authorities, what risk of illness he or she finds acceptable and act accordingly. Three equations (Table 3), each corresponding to a criterion, are available for predicting swimming-associated rates of acute gastroenteritis from enterococcus monitoring data.

TABLE 3 Predictive Equations for Swimming-Associated Gastroenteritis^a

<table>
<thead>
<tr>
<th>Value</th>
<th>U.S.</th>
<th>Cairo visitors</th>
<th>Alexandria residents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope</td>
<td>12.17</td>
<td>20.290</td>
<td>5.481</td>
</tr>
<tr>
<td>Intercept</td>
<td>0.02</td>
<td>-37.068</td>
<td>-4.842</td>
</tr>
<tr>
<td>r</td>
<td>0.75</td>
<td>0.88</td>
<td>0.68</td>
</tr>
</tbody>
</table>

^a See Cabelli (1980) for the data base; Y on X equation predicts the illness rate/1000 swimmers (Y) corresponding to a 50 or 90 percentile log_10 enterococcus level/1000 ml in the bathing water (X).

RESEARCH AND DATA NEEDS

Data from three types of epidemiological-microbiological studies are urgently needed. The first is a study in which tourists from a country in which environmental sanitation is well developed swim at beaches in countries or...
areas where there is a high rate of enteric disease. The second is a study at a site where reasonably low enterococcus levels in the bathing water can only be attained by the chlorination of wastewater effluents from nearby outfalls. The third need is for additional data from prospective epidemiological studies in which drainage or stormwater run-off results in high enterococcus levels but in which there is no extrinsic source of human fecal wastes. The final need is for an indicator which is specific for human fecal wastes or, at least, municipal wastewater effluents and which better mimics the survival of the Norwalk virus during wastewater chlorination and transport in the aquatic environments.

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