Association Between Coastal Water Exposure and Urinary Tract Infection in Adult Females

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SYNOPSIS: This paper describes a study of female beachgoers in Santa Cruz and found that swimming in coastal waters significantly increased the risk of urinary tract infections (UTIs), with the risk rising based on the level of water submersion and ingestion.

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ABSTRACT

Gastrointestinal illness is a known risk of swimming in coastal waters which are contaminated by sewer overflows, septic tanks, domestic pets, or wildlife. Limited research has assessed the risk of urinary tract infections (UTIs) from recreating in coastal waters, even though they are an established reservoir of UTI pathogens. We performed a prospective study of beachgoers in Santa Cruz, California over the summer of 2022 to examine the association between baseline recreational water and sand contact and subsequent UTI symptoms among adults who were assigned female at birth. We additionally analyzed surveillance data on fecal indicators in the same recreational water on dates when participants enrolled in the study. We observed significant increases in gastrointestinal illness and UTI among swimmers compared to non-swimmers. UTI risk was associated with the type of exposure; odds ratios (ORs) increased from waist deep submersion (OR = 3.1; 95% CI: 1.4-6.9) to head submersion (OR = 5.1; 95% CI: 1.7-18.9) to swallowed water (OR = 8.69; 95% CI: 2.2-33.9). Among water quality samples across sites and study dates, 15% exceeded advisory thresholds, including fecal coliform, *Enterococcus*, and *E. coli* limits. These results suggest a need to better characterize dose-response relationships between exposures to fecally contaminated recreational water and UTI risk.

INTRODUCTION

Marine beaches are popular destinations for recreation and tourism worldwide. Swimming in coastal waters can be accompanied by measurable illness risk, primarily attributed to fecal contamination of these bodies of water. Discharges of wastewater, agricultural and industrial runoff, and local wildlife can contribute microbial pathogens that make recreational waters high risk sites for infections[1].

Swimming in fecally-contaminated waters has a strong and well-established association with gastrointestinal (GI) illness[2-5]. Accordingly, the safety of marine waters for human contact is determined by risk of gastrointestinal illness[5]. Fecal indicator bacteria (FIB) such as *E. coli* and *Enterococci* are measures of contamination that are positively correlated with fecal-borne pathogens that cause GI illness. FIB have demonstrated a predictive relationship with gastrointestinal illness among swimmers and are widely used to determine safety thresholds and public contamination warnings[6]. Different microbial methodologies for measuring FIB, however, can vary in their predictive capability[7]. Marine shoreline sands serve as an ideal reservoir for FIB derived from terrestrial and aquatic sources[8] and contact through digging or submersion in sand is similarly associated with GI illness symptoms[9].

Fecal-borne pathogens incur illness risk beyond the GI tract; prior shoreline epidemiology studies have measured risk of sinus symptoms, upper respiratory infection, open wound infection, skin rash, and eye problems associated with recreational activity in contaminated marine waters[10-13]. While UTI risk has been attributed to ascendant contamination of the urinary tract by fecal bacteria through wiping, catheterization, or sexual intercourse[14-16], few studies have evaluated the risk of UTI incurred by swimming in fecally contaminated marine waters.

Uropathogenic *Escherichia coli* (UPEC), commensal intestinal bacteria, which contain virulence properties to the urinary tract, are the most common cause of community-acquired UTI[17]. *Klebsiella pneumoniae*, *Proteus mirabilis*, *Enterococcus faecalis*, and *Staphylococcus saprophyticus*, which also colonize the intestine and qualify as fecal pathogens, account for the remaining causes of community-acquired UTI[14]. Fecally-contaminated waters, such as those receiving treated wastewater, are a known reservoir of UPEC[18]. In a population-based case-control study of patients with culture positive UTI, 'seawater swimming in the prior year' was an independent risk factor for UTI caused by ESBL-producing *E. coli*[19]. This risk was notably lower than that conferred by recent travel, recent use of fluoroquinolones and β-lactams, and diabetes. The highest incidence of UTI occurs during the late summer months and is associated with warmer water temperatures and heat waves[20, 21]; these are also months when recreational water use is the highest.

The goal of this study was to examine the risk of UTI from recreational water and sand contact along a coastline in Santa Cruz, California. People who were assigned female at birth (females from here forward) are disproportionately predisposed to UTI by anatomical factors: the urethra is shorter and more proximal to the rectum in this population[22]. UTI in the postnatal pediatric population occurs most frequently in individuals with structural anomalies of the genitourinary tract; outside of these conditions, endemic prevalence of UTI is significantly lower in pediatric populations until onset of sexual activity[23]. Accordingly, this study was pre-stratified to examine the specific genitourinary and gastrointestinal outcomes among adult female beachgoers following their exposure to marine water and beach sand.

MATERIALS AND METHODS

Study Design. This study followed a prospective cohort, similar to a prior investigation of shoreline gastrointestinal illness risk[9, 12, 24-26]. The study included symptom screening of beachgoers through online questionnaires and traditional water quality sampling on participant enrollment days.

All study instruments and protocols were approved by the Committee for the Protection of Human Subjects at the University of California, Berkeley (Protocol ID # 2022-04-15241).

Study Sites. The study was conducted at contiguous beaches along the Santa Cruz Coastline: Cowell Beach, Santa Cruz Main Beach, and Seabright State Beach. The Santa Cruz boardwalk attracts three million visitors annually. The study sites were selected because of the large number of visitors during the summer months and the presence of many sources of FIB. An estimated 8.3 million gallons per day of treated wastewater (secondary treatment) is discharged one mile offshore of Cowell Beach. Additionally, the San Lorenzo river, which discharges between Santa Cruz Main Beach and Seabright State Beach, is a major freshwater source of FIB, largely attributable to wildlife and household septic systems. During the summer months, the San Lorenzo river is lagooned off periodically with intermittent and irregular releases to the ocean. The end of the river, however, remains open for recreation.

Beach Recruitment. Beachgoers were recruited at Cowell Beach, Santa Cruz Main Beach, and Seabright State Beach on weekends and weekdays throughout the summer of 2022, beginning June 22nd and continuing through August 27th. Participants were enrolled from 9am to 5pm over the course of 28 total days.

Eligibility criteria included the following: no previous participation in the study; 18-years or older; assigned female at birth; no history of swimming (waist deep) in the ocean or in a lake in the prior 7 days; and internet access through computer or smartphone. If an individual was eligible and agreed to participate, they provided written consent. Participants were given a beach ball as an incentive for participation and asked to complete a questionnaire sent via text or email – according to their indicated preference – that evening. The questionnaire assessed individually reported exposure level at the beach and symptoms experienced in the prior 3 days. Participants who failed to complete the survey that evening were reminded within 3 days by text or email.

Water Quality Data Collection and Analysis. The City and County of Santa Cruz collected water samples on enrollment dates (between 8am and 11am) and tested them for four traditional indicators: *Enterococci*, *E. coli*, fecal coliforms, and total coliforms. One sample was obtained at each collection point per enrollment day. Sample collection locations are shown in Figure 1. The City of Santa Cruz measured Enterococci, fecal coliforms, and total coliforms by membrane filtration methods: EPA 1600, Standard Method 9222D, and Standard Method 9222B, respectively[27, 28]. On alternate days, Santa Cruz County measured *Enterococci*, *E. coli*, and total coliforms by traditional IDEXX detection methods[28].

Figure 1: City and County Water Quality Sampling Sites, Santa Cruz, California 2022

Follow-Up Survey. Approximately 14 days after their beach visit, study participants were emailed or texted according to their indicated preference and asked to complete a ten-minute survey. The survey included questions on demographic information, swimming and other exposures since the time of their beach visit, pre-existing health problems associated with gastrointestinal and genitourinary symptoms, behaviors at the beach such as shower use and wetsuit use, and acute illness symptoms experienced since the visit to the beach. Participants who failed to complete the survey that day were reminded by repeat text or email the next day and by a phone call the following day.

Health Outcomes Measured. Health outcomes included gastrointestinal symptoms and genitourinary symptoms. Gastrointestinal symptoms included nausea, vomiting, diarrhea, fever, and stomach cramps. Diarrhea was defined as three or more loose or watery stools per day[29]. Individuals who experienced any of the following symptoms were designated as having highly credible gastrointestinal illness (HCGI) as defined by previous studies[26, 30]: diarrhea; or vomiting; or nausea and stomach cramps; or nausea and missed daily activities due to illness; or stomach cramps and missed daily activities due to illness. Genitourinary symptoms included dysuria, hematuria, urgency, urinary frequency, urinary hesitancy, suprapubic pain, incomplete urination, leakage, and straining. UTI was defined in the absence of urine sampling per previous studies[31, 32] as having three or more of the aforementioned symptoms simultaneously in the absence of vaginal discharge, vaginal irritation, or menstrual period. Presence of vaginal irritation or discharge reduces the probability of UTI in individuals with concomitant urinary symptoms, where sequela is more fittingly attributed to sexually transmitted infection, yeast infection, or bacterial vaginosis[33]. Respondents who reported symptoms within the 3 days prior to their beach visit or on the day of their visit were excluded from analysis for that outcome. For example, participants who reported symptoms of HCGI were excluded from analysis for HCGI risk, but not UTI risk.

Exposure Measured. Exposures at baseline were captured in the initial follow up survey the evening of the beach visit. The type of water exposure was separated into three categories based on self-reported minimum exposure: 1) waist deep body immersion, 2) head immersion, and 3) swallowed water. Additionally, sand contact was defined as sitting directly in the sand without a towel.

Data analysis. We began by assessing HCGI and UTI rates among different exposure categories: waist deep body immersion, head immersion, swallowed water, no sand contact, sat directly in sand. Non-swimmers were considered individuals who did not immerse to waist depth at any point during their visit to the beach.

Logistic regression was used to compare the association of gastrointestinal and genitourinary symptoms between swimmers and non-swimmers and between those with and without sand contact at baseline. HCGI and UTI were treated as separate binary illness outcomes. The log odds of illness was modeled by logistic regression:

$$\ln\left(\frac{p}{1-p}\right) = \alpha + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3$$

where p is probability of illness, x_1 is a variable for any water contact, x_2 is a dichotomous indicator variable for water contact beyond waist deep (head immersion, swallowed water), and x_3 is a vector of potentially confounding covariates.

An additional regression was used to determine the association between the risk of illness and sand contact, where p is probability of illness, x_1 is a variable for any sand contact and x_3 is a vector of potentially cofounding covariates. Relative risk of illness due to sand exposure was estimated as $OR = \exp(\widehat{\beta_1})$.

HCGI and UTI outcomes were adjusted for covariates (x_3) that were associated with the respective outcome or potential confounders. The following variables were considered for both outcomes: age, swimming in the ocean since enrollment, swimming in a pool or jacuzzi since enrollment, antibiotic use in the past three months, and hospitalization in the past three months. All covariates except age were categorized as 1 and 0. HCGI models also considered the following binomial covariates: household member with a gastrointestinal illness or food poisoning, and chronic gastrointestinal condition. UTI models considered the following additional covariates: prior UTI, history of recurrent UTI defined as ≥ 3 UTIs in 12 months or ≥2 UTIs in 6 months[34, 35], chronic illnesses associated with UTI and urinary symptoms such as diabetes mellitus and kidney disease[36], sexual activity in past month, and urinary catheter placement in past month. Consistent with prior investigation of shoreline illness risk[12, 25, 26], covariates were chosen for each model using a change in estimate algorithm which selected variables that modified the estimated OR by 5% when removed from multivariate analysis[37]. The models adjusted for covariates and estimated an OR and correspondent 95% confidence interval (CI) calculated using robust standard errors[38].

RESULTS

We enrolled 1514 eligible female beachgoers, 837 of which (55%) completed the first evening follow up about their beach activity and 586 completed the final follow up 2 weeks later (39% retention). Among the individuals who completed all follow up, 33% (191 individuals) had some form of water contact on the day of enrollment and 37% (216) sat directly in the sand. Among the individuals who were lost to follow up, 27% (67) had some form of water contact and 37% (92) sat directly in the sand. Demographics were similar across the different exposure groups (Table 1). Participants were asked in their initial follow up if speaking to the study team affected their decision to go into the water: nine percent indicated their decision was affected and six percent did not go in the water altogether as a consequence of the enrollment process (Table 2).

Characteristic	All	No Water Contact	Body Immersion	Head Immersion	Swallowed Water	No Sand Contact	Sat Directly in Sand
Completed Follow up	586	395	191	88	46	370	216
Lost to follow up	251	184	67	23	11	159	92
Age*							
18-29	37.0%	32.2%	47.1%	48.9%	50.0%	33.0%	44.0%
30-41	26.3	26.1	26.7	19.3	23.9	25.1	28.2
42-53	22.9	26.1	16.2	15.9	15.2	25.9	17.6
54-65	8.0	8.4	7.3	11.4	6.5	8.9	6.5
66+	4.6	6.1	1.6	3.4	2.2	5.9	2.3
Missing	1.2	1.3	1.0	1.1	2.2	1.1	1.4
Household Income*							
< $10,000 - $25,000	8.0%	7.1%	9.9%	12.5%	15.2%	5.9%	11.6%
$25,001 - $50,000	11.3	11.1	11.5	9.1	8.7	11.1	11.6
$50,001 - $75,000	10.9	10.1	12.6	9.1	6.5	8.1	15.7
$75,001 - $100,000	10.2	10.4	9.9	10.2	13.0	11.9	7.4
$100,001 - $150,000	15.7	15.4	16.2	13.6	8.7	16.8	13.9
> $150,000	21.8	24.6	16.2	18.2	19.6	23.8	18.5
Missing	22.0	21.3	23.6	27.3	28.3	22.4	21.3
Education Status*							
<High School - High School	18.9%	16.5%	24.1%	23.9%	21.7%	17.0%	22.2%
Trade School or Community College	23.0	23.3	22.5	21.6	26.1	21.6	25.5
Bachelor's Degree	34.1	35.4	31.4	30.7	26.1	37.0	29.2
Master's or Professional Degree	18.1	19.0	16.2	19.3	17.4	19.5	15.7
Doctoral Degree	3.4	4.1	2.1	2.3	4.3	3.8	2.8
Missing	2.4	1.8	3.7	2.3	4.3	1.1	4.6

*Characteristics of individuals who completed follow up

Table 1. Characteristics of Study Population by Level of Exposure, Santa Cruz, California, 2022

	All	No Water Contact	Any Water Contact	No Sand Contact	Sat Directly in Sand
Study affected choice to swim	75	50	25	45	30
Gastrointestinal Illness					
Diarrhea Episodes	58	32	26	35	23
Wetsuit	7	—	7	2	5
Onsite Shower use	6	—	6	3	3
Gastrointestinal Illness, episodes	83	45	38	48	35
Wetsuit	7	—	7	2	5
Onsite Shower use	7	—	7	4	3
Missed Daily Activities	59	32	27	39	20
Medical Visits	9	5	4	6	3
Genitouriniary Illness					
Urinary Tract Infection, episodes	30	11	19	12	18
Wetsuit	5	—	5	2	3
Onsite Shower use	3	—	3	1	2
Missed Daily Activities	24	12	12	2	22
Medical Visits	11	6	5	6	5

Table 2. Illness Outcomes by Level of Exposure and Onsite Behaviors

Among participants without any water contact, 11.39% experienced an episode of HCGI during the 2-week follow up period (Table 3). This incidence exceeds control estimates from prior shoreline monitoring studies[12, 25, 26] whose study population also included people under the age of 18 and people who were assigned male at birth (AMAB). Incidence of HCGI progressively increased with water contact: 19.90% for waist deep submersion, 20.45% for head submersion, and 23.91% for those who swallowed water. The adjusted OR of HCGI in swimmers as compared to non-swimmers decreased with increasing water contact: waist deep submersion (aOR = 2.27, 95% CI 1.26-4.13), head submersion (aOR = 2.07, 95% CI 0.55-7.71), and swallowed water (aOR = 1.74, 95% CI 0.68-4.42). Prior studies have shown a converse relationship—gastrointestinal illness risk typically has a dose-dependent response to water contact[12, 25, 26].

Water Exposure

Health Outcome	No Water Contact (*N* = 395) % Ill	Waist Deep (*N* = 191) % Ill	Waist Deep Adjusted OR* [95% CI]	Head Submerged (*N* = 88) % Ill	Head Submerged Adjusted OR* [95% CI]	Swallowed Water (*N* = 46) % Ill	Swallowed Water Adjusted OR* [95% CI]
HCGI	11.39	19.90	2.27 [1.26-4.12]	20.45	2.07 [0.55-7.71]	23.91	1.74 [0.68-4.42]
UTI	2.78	9.95	3.07 [1.37-6.88]	13.64	5.07 [1.36-18.92]	21.74	8.69 [2.23-33.89]

Sand Exposure

Health Outcome	No Sand Contact (*N* = 370) % Ill	Sat Directly in Sand (*N* = 216) % Ill	Sat Directly in Sand Adjusted OR** [95% CI]
HCGI	12.97	16.20	1.17 [0.69-1.97]
UTI	3.24	8.33	1.94 [0.87-4.31]

HCGI, highly credible gastrointestinal illness
UTI, urinary tract infection
*Odds Ratio using non-swimmers as the reference group.
**Odds Ratio using no sand contact as the reference group.

Table 3. Associations between Gastrointestinal & Genitourinary Illness and Swimming for Various Levels of Water and Sand Exposure.

Non-swimmers had a 2.78% incidence of UTI during the study period, which amplified with progressively increasing water contact. Illness rate was 9.95% among waist deep swimmers, 13.64% among head submersion swimmers, and 21.74% among those who swallowed water. Adjusted OR of UTI for swimmers compared to non-swimmers indicated a dose-dependent response: waist deep submersion (aOR = 3.07, 95% CI 1.37-6.88), head submersion (aOR = 5.07, 95% CI 1.36-18.92), and swallowed water (aOR = 8.69, 95% CI 2.23-33.89). Onsite behaviors such as shower use and wetsuit use among individuals who experienced HCGI and UTI during the study period are shown in Table 2, alongside missed daily activities and medical visits due to illness.

Among participants who did not sit in the sand during their beach visit, 12.97% experienced HCGI during the study period and 3.24% experienced UTI. The adjusted OR for HCGI and UTI among those who sat in sand compared to those who did not indicate a significant association between sand contact and both ailments: HCGI associated with sand contact (aOR = 1.17, 95% CI 0.69-1.97), UTI associated with sand contact (aOR = 1.94, 95% CI 0.87-.431).

Water Quality. During the study period, 393 water samples were collected and analysed by the City and County of Santa Cruz, corresponding with study participant enrollment days (Table 4). Among these samples, 58 (15%) exceeded advisory thresholds[6]. Merged *Enterococci* analysis from City and County methodologies resulted in 24 violations (>104 CFU/100mL) distributed across the study sites. *Enterococci* concentrations ranged from 1 to 11,100 CFU/100mL; detectable samples averaged 86 CFU/100mL. Analysis for total coliforms yielded three violations (>10,000 CFU/100mL), concentrated at the San Lorenzo River outfall site. Total coliforms ranged from 6 to 24,196 and averaged 1,817 CFU/100mL. The city performed fecal coliform testing, which resulted in 23 violations across 88 samples, while the county performed *E. coli* analysis on their respective sample sites, which resulted in 8 violations across 43 samples.

Indicator	Method	Units	N	Min	Max	Non-detects
Enterococcus	Enterolert	MPN/100mL	43	20	422	23
Enterococcus	Standard Method 9230C, EPA 1600	CFU/100mL	88	1	11,100	6
E. coli	Colilert	MPN/100mL	43	20	17,329	12
Fecal Coliform	Standard Method 9222D	CFU/100mL	88	2	20,000	1
Total Coliform	Colilert	MPN/100mL	43	20	24,196	3
Total Coliform	Standard Method 9222B	CFU/100mL	88	6	2,400	6

Table 4. Concentration of Fecal Indicator Bacteria at study sites during enrollment days

DISCUSSION

This prospective cohort study is one of the first to demonstrate a clear association between UTI symptoms and recreational marine water exposure in AFAB adults. The results showed that progressive levels of exposure to recreational waters (waist deep, head submerged, swallowing water) incur increased incidence and risk of acquiring UTI compared to unexposed beachgoers. While it was not the primary focus of our study, we also investigated the incidence of HCGI per previously established definitions. HCGI served as an ideal positive control because illness risk is well established for this exposure. Similar to UTI, HCGI classification relies on a mosaic of symptoms which makes it an apt comparator. However, unlike previous shoreline illness investigations, our study used a pre-stratified population: female adults. We found that water exposure was associated with an increased incidence of HCGI, which was amplified with progressive exposure. The incidences of HCGI were 5 to 6-fold higher among non-swimmers and swimmers at all levels of exposure than those produced by previous studies[12, 25, 26]. While relative risk of HCGI was also significantly increased by any water exposure, defined as minimum waist-deep swimming, illness risk did not increase significantly with higher levels of exposure. Our study did not demonstrate a dose-dependent HCGI risk as in previous studies[12, 25, 26]. Such studies notably reported lower incidence of HCGI among control participants, whereas our study indicated a greater than ten percent incidence of HCGI at baseline in the study population without water contact. This difference may have been introduced by differential recall bias inherent to our recruitment and survey methodology which focused on UTI symptomology. However, the initial sub-stratification may have also been contributory: female individuals experience a greater incidence of HCGI symptoms at baseline than their male counterparts[39].

We also observed that sand exposure was associated with increased incidence and adjusted OR of HCGI and UTI. Our study defined sand contact as directly sitting in sand and finding sand in swim trunks. Prior examination of HCGI in association with sand contact used different definitions of sand exposure, such as digging or being buried in sand, which were not captured in our questionnaires[9]. For all levels of contact including controls, incidences of HCGI were greater than that of UTI. However, adjusted OR among swimmers and individuals who sat in sand when compared to their respective controls were consistently higher for the UTI outcome than the HCGI outcome, indicating a lower incidence but higher risk of UTI in this subpopulation.

Onsite behaviors such as shower use and wetsuit use were captured during participant's first follow up. While the study population was not large enough to draw significant conclusions about how these behaviors interacted with illness risk, in both outcomes, it is worth mentioning that individuals who wore wetsuits and showered onsite each represented less than one-quarter of the sick respondents. Water quality analysis indicated that many recruitment sites experienced fecally-contaminated water at different points during the study period. The outlet of the San Lorenzo River was the only study site to exceed the total coliform threshold of 10,000 CFU/100mL during the study period. Since the sample size was not sufficient for illness risk modeling of FIB concentrations, a future study should focus on determining the association between FIB concentration and UTI, which remains unexplored. While incidence of gastrointestinal illness among swimmers has a known association with presence of FIB, other illnesses such as ear infection have an association with marine water exposure but *not* bacteria levels[10, 26]. Determining whether the UTI belongs to the former or the latter group has implications for water quality monitoring. Future studies should aim to elucidate whether UTI risk is attributable to bacterial inoculation from contaminated waters versus a more insidious disruption of the healthy urinary microbiome.

The results of our study are similar to previous studies about parasitic urogenital schistosomiasis in endemic regions, which showed a strong association between disease and water contact[40, 41]. A prior UTI study, whose sample population was 41.9% under the age of 20 and 47.4% assigned male at birth, examined illness risk from non-point source contaminated marine waters and yielded UTI incidences of less than one percent across exposures; adjusted OR showed dose response with insignificant confidence intervals[24]. The much higher incidence of UTI in our study may be attributed to the pre-stratification and categorization methodology. Our study used symptomatic criteria to categorize participants as having a UTI, a method inherently more prone to recall bias than classic laboratory diagnosis of UTI. However, laboratory-based methodology is also prone to erroneous inclusion of participants with asymptomatic bacteriuria. Future studies should aim for a classification system which integrates both urinalysis and symptomatology in alignment with current clinical diagnostic processes[42].

The particularly elevated risk of UTI among individuals who swallowed water is suggestive of a potential oral to rectal to urethral route of uropathogens over the study period. Pathogenic alterations in the gut microbiome have been noted to occur in the days preceding UTI in infants, offering a possible mechanism by which oral intake may affect gut colonization and by proxy rectal to urethral transfer of uropathogenic bacteria[43]. Among the individuals who swallowed water and experienced subsequent UTI, 20% experienced a diarrheal episode after their beach visit but prior to the onset of their UTI symptoms. Traveler's diarrhea is a known risk factor for UTI[44]. Our findings suggest that immune status after diarrheal illness may elicit UTI, as has been observed in respiratory infection[45]. It is also possible that diarrhea itself serves as a nidus of uropathogens which are more readily exposed to the urethra through known behavioral risk factors such as sexual activity. Future studies should continue to capture intestinal symptoms alongside UTI screening to evaluate the nature of water-associated diarrhea as a risk factor for UTI. It is also possible that swallowing water represents a confounder for high risk behavior, which may also contribute to increased UTI risk.

Our results are limited by loss to follow-up despite efforts to contact participants: 677 enrollees failed to complete the first evening follow-up, and 251 were lost to the final 2-week follow-up. The baseline characteristics of those who did complete the study and those who did not are similar, suggesting that systematic bias was not present. UTI outcomes were potentially biased by the absence of culture confirmation; however, symptomatic composition among unexposed and exposed individuals with UTI were fairly consistent.

The results of this study are sufficiently compelling to warrant future studies that better characterize dose-response relationships between exposures to fecally contaminated recreational marine water and culture-confirmed UTI in female adults. Understanding the dose-response relationships, as well as potential interventions to reduce UTI risks would be beneficial to future surveillance and control programs.

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