Assessment of Water Use for Estimating Exposure to Tap Water Contaminants

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Epidemiological studies examining the association between exposure to tap water contaminants (such as chlorination by-products) and disease outcomes (such as cancer and adverse reproductive outcomes) have been limited by inaccurate exposure assessment. Failure to take into account the variation in beverage and tap water consumption and exposure to volatile contaminants through inhalation and dermal absorption can introduce misclassification in assessing the association between exposure to tap water contaminants and health. To refine exposure assessment of tap water contaminants, we describe in detail the tap water consumption, showering, and bathing habits of pregnant women and their male partners as assessed by a questionnaire and a 3-day water diary. We found good agreement between questionnaire and 3-day water diary values for drinking water intake (Pearson’s $r = 0.78$) and for time spent showering ($r = 0.68$) and bathing ($r = 0.78$). Half of the participants consumed tap water on a regular basis with an overall mean ± 1 standard deviation (SD) of 0.78 ± 0.51 l/day. Our results further suggest that full-time employees, compared to women working part-time or less, have more heterogeneous consumption patterns over time. Seventy-nine percent of women and 94% of men took showers for an average of 11.6 ± 4.0 min and 10.4 ± 4.8 min, respectively. Baths were taken more frequently by women than men (21% vs. 3%) for an average of 22.9 ± 10.1 min and 21.3 ± 12.4 min, respectively. Thus, these patterns of tap water use should be considered in the design and interpretation of environmental epidemiology studies. 

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The main methodological difficulty with epidemiological studies that examine the association between tap water contaminants, including chemical and microbial agents, and disease outcomes lies in accurate assessment of individual exposure to tap water. Often, exposure to tap water is classified by the source of water (i.e., ground or surface supply), the type of water treatment, the concentration of the tap water contaminant at the water utility serving the participant’s residence, or some combination of the three. Broad exposure definitions, which do not take into account intra- and interindividual sources of variation either in tap water concentrations of the contaminant or in individual tap water consumption, can introduce exposure misclassification and thereby distort associations between tap water exposure and adverse health outcomes (1). In addition, recent studies have shown that exposure to volatile tap water contaminants through inhalation or dermal absorption may be equal to or greater than exposure through ingestion (2). Thus, the assessment of showering, bathing, and swimming habits can be important when evaluating tap water exposure.

This report provides information for developing exposure assessment methods for epidemiologic studies of adverse health effects associated with tap water exposure.

We describe in detail the tap water consumption, showering, and bathing habits of pregnant women and their male partners as assessed by a questionnaire and a 3-day water diary. We also consider a range of possibly important behaviors that may affect tap water exposure, such as location of tap water consumption, frequency of showers, and duration of baths. We examine the pattern of variation in tap water consumption over time and across individuals and compare the questionnaire data with the water diary data to evaluate the consistency between methods of data collection.

Materials and Methods

Subject selection. From October 1994 to January 1995, potentially eligible participants were identified by reviewing the medical records of the Obstetrics and Gynecology Clinic of the University of North Carolina Hospitals, Chapel Hill, North Carolina. Initially, the study was restricted to women who were no more than 14 weeks pregnant at the time of medical record review, had at least 10 years of schooling, lived with their male partners, and resided within the service area of the local water utility (the Orange Water and Sewer Authority). To obtain a sufficient number of participants, the inclusion criteria were expanded in December 1994 to include women who were up to 30 weeks pregnant and who lived outside the aforementioned service area.

Participants were initially contacted by mail; if they did not refuse to participate at that time, the interviewer called to recruit them for the study and arrange a time for a home interview. Both the woman and her partner were asked to participate. Out of 79 couples initially identified during the medical record review, 71 (90%) actually met the eligibility criteria. Of these, 19 declined by mail (27%), 16 declined by phone (23%), and 36 were interviewed (51% of those eligible). Informed consent was obtained from all interviewed participants. Of those 36 couples who were interviewed, 33 couples and one woman (but not her partner) completed the 3-day water diary. Only those who completed both the interview and water diary were included in the analysis.

Interview and water diary. During the interview, participants provided information about daily water consumption and weekly consumption of cold water-based beverages that had been prepared in the home during the previous 3 months. Questions were asked about how long beverages were typically stored and whether the storage container was open or closed. We distinguished among beverages that were made from filtered tap water, unfiltered tap water, and bottled water. Filtered tap water was defined as tap water that had been filtered using an activated carbon point-of-use device. The interviewer also gathered information about the frequency and duration of baths and/or showers. The level of ventilation while bathing was addressed by asking the participants about whether they usually kept the bathroom door open or closed, bathroom window(s) open or closed, and the ventilation fan on or off while bathing. The frequency and duration of other water-related activities such as swimming (including water aerobics and use of jacuzzis); bathing children or pets; washing dishes,
clothes, or cars by hand; mopping floors; and frequent handwashing were also ascertained.

At the time of the interview, participants were instructed on how to complete the prospective water diary. For each day of the study, participants were asked to record every beverage they consumed, its volume and temperature (cold or hot), where and when it was consumed, and whether it was prepared with tap or bottled water. Unfortunately, filtered tap water was not an option listed on the diary record form. For eight participants, the type of water question was inadvertently omitted altogether. Frequency and duration of exposure to tap water via showering and bathing, swimming, bathing children, washing dishes or clothes by hand, or by some other activity were also recorded. The participants were allowed to choose which 3 days they recorded in their water diary, although they were asked to commit to the days agreed upon during the interview. They were instructed to choose at least one nonworking or weekend day and to complete the diary at a time when they were in town and healthy. Eighty-two percent of households completed the water diary within 1 week from the date of interview.

With the exception of the comparison between water diary records and interview data, missing information (320 incomplete diary entries from 35 participants) was imputed to avoid excluding the entire diary of that participant from the other analyses. Where possible, the missing information was imputed from the interview since similar questions were asked in both the interview and the diary. Otherwise, similar assumptions as those by Ershow and Cantor (3) were made: milk, juices (except reconstituted frozen fruit juices), alcoholic beverages, and soft drinks were assumed to be made from bottled water; water, powdered drinks, coffee, and tea were assumed to be made from unfiltered tap water (3). Information on selected missing beverage volumes and locations (comprising 0.3% of all beverage entries) was imputed using information from adjacent diary record entries. Where beverage temperature was missing, beverages were assumed to be cold, except for coffee and tea, which were assumed to be hot. All iced tea beverages were considered to be hot beverages because it was assumed that they were heated during preparation, although no differentiation was made between instant and brewed tea.

Statistical methods. For each day of the water diary, the total volume of 1) all beverages (hereafter referred to as total water), 2) drinking water and beverages made with tap water (hereafter referred to as tap water), and 3) cold drinking water and tap water beverages consumed at home (hereafter referred to as cold tap water consumed at home) were calculated and averaged over the participant’s 3 days of water records. Consumption of each beverage type for female and male participants was summarized by calculating the mean and standard deviation (SD), along with selected percentiles, of the overall distribution. For female participants, the distribution of daily intake of cold tap water consumed at home was also stratified by employment status. Male participants were not stratified by employment status because nearly all (85%) male participants were employed full time.

Because location of consumption (home or other location), temperature of beverage, and type of cold beverage (drinking water or tap water-based beverage) are potentially important determinants of tap water exposure, tap water consumption was stratified by these factors. Means of total water, tap water, and cold tap water consumption were compared across sex and employment status (full time, not full time) using analysis of variance. Of those female participants who consumed tap water at home, the percentage of participants who stored any tap water beverage, the average number of days stored for each beverage type, and the percentage of containers that were closed were analyzed separately for drinking water and tap water-based beverages.

The frequency and duration of showers and baths were determined, as well as the frequency of nonventilated showers in winter and summer. A nonventilated shower was defined as a shower where the bathroom door and window (if present) were closed and the ventilation fan (if present) was off.

The pattern of variation over time (i.e., from one day to the next) and across individuals was examined using the 3-day diary information on daily consumption of filtered cold drinking water (iced tea excluded). By employing a one-way random-effects analysis of variance model, these (natural log-transformed) data were used to estimate the between-person and within-person components of variance (because some participants reported no daily consumption of drinking water, I was added to each value before logarithms were computed). Variance components were estimated separately for male and female participants and for female participants employed full time or employed part-time or less. The intraclass correlation coefficient (ICC), defined as the percent of total variance due to the between-person variance component, was estimated as well. Because of the inherent bias of this formula, the results using this formula were confirmed using an unbiased but more intricate ICC formula (4).

To compare the questionnaire data with the water diary data (3-day averages), Pearson’s and Spearman’s correlation coefficients were computed. Comparisons were also made by evaluating the mean difference between values obtained from the two data collection methods. Differences were determined for each participant first and then the average and 95% confidence interval (CI) of all the differences for the study population were calculated (5). We compared three values, one for each route of exposure: volume of drinking water consumed per day at home (tap water-based beverages were excluded because volume estimates from the interview data were not obtained), the total number of minutes spent showering per day, and the total number of minutes spent bathing per day. All analyses were conducted using the Statistical Analysis System version 6.10 (SAS Institute, Cary, NC).

Results

Participant characteristics. Thirty-four pregnant women and 33 of their male partners completed both the water diary and the interview. Overall, they tended to be highly educated non-smokers in their twenties or thirties and having their first child (Table 1). Three-fourths of the participants were white, with the remainder split evenly between African-American and Asian ethnicities. Although the women’s gestational ages ranged from 12 to 37 weeks, most (59%) were in their second trimester of pregnancy. Men were much more likely to be employed than women, though they were equally likely to be students. About half of the participants consumed tap water at home on a regular basis, and the majority (82%) was served by treated water supplies.

Daily water consumption. Consumption of total water, tap water, and cold tap water at home (Table 2) as reported by the questionnaire indicates that participants consumed on average close to the National Academy of Sciences’ standard assumed intake of 2 liters water/day (6), but less than 20% was cold tap water at home. Overall, men and pregnant women had similar water consumption habits, and only cold tap water consumption at home differed by employment status.

Table 3 shows mean daily tap water consumption by location, temperature, and beverage type (drinking water or tap water-based beverage) as reported by the questionnaire. Women employed part-time or less consumed the most tap water overall, but total consumption levels among sex and employment groups did not vary significantly (p>0.10). Women employed part-time or less averaged the most tap water consumption at home (due to consuming more drinking water), whereas outside the
home, men consumed the most tap water (due to consuming more hot tap water). Differences in consumption patterns by sex were less pronounced relative to differences in consumption by extent of employment (full time vs. not full time), suggesting that employment status is a stronger determinant of tap water consumption patterns than sex.

Slightly over half (53%) of the women drank tap water at home. Of those, 28% stored the water for an average interval (± 1 SD) of 1.4 ± 0.8 days. In contrast, of women who consumed at least one tap water-based beverage (59%; n = 20), all stored the beverage an average interval (± 1 SD) of 5.1 ± 3.1 days. Most (89%) beverage containers were closed during storage.

The large proportion of total variance due to between-person variance in women working part-time or less (ICC = 0.81, with a total variance of 8.75) suggests that almost all the variability in unfiltered cold tap water consumption habits is due to individual differences, with very little day-to-day variability. On the other hand, full-time employed women and men had much lower between-person variance (ICC = 0.42, with a total variance of 7.38, and ICC = 0.49, with total variance of 8.80, respectively), indicating greater heterogeneity in consumption patterns over time, possibly between workdays and nonworkdays. Overall, among all women, 61% of total variance was due to between-person variance (ICC = 0.61, with a total variance of 7.83). A comparison of results between the applied ICC formula with a second unbiased formula resulted in negligible differences.

Showering, bathing, and other water-related activities. Nearly all participants reported showering (90%); of those, all but nine showered at least daily for an average of about 10 min, with women tending to shower longer than men (Table 4). More men than women showered, and more showers were ventilated in summer than in winter. Women took more baths than men; of those who reported bathing (22%, n = 15), almost half reported daily bathing. Baths lasted on average twice as long as showers.

Swimming was reported for only five (7.5%) of the study participants during the interview; of those, only one reported swimming in her water diary. However, because this study was conducted in the winter, assessments made at other times of the year are likely to yield very different results. The discrepancy between the questionnaire and the water diary may be due to the fact that swimming is not a daily activity and therefore may not have been well represented during the 3 days of the water diary. The other water-related activities were too diverse to be evaluated, but washing dishes was the most commonly reported activity, while occupational exposures such as watering gardens and milking cows were the most time intensive.

**Table 1. Selected lifestyle, physical, and demographic characteristics of study participants**

| Demographic variable | Female (n = 34) | Male (n = 33)* |
|----------------------|----------------|---------------|
| Education (%)        |                |               |
| Some college         | 15             | 9             |
| College graduate     | 24             | 20            |
| Some graduate/professional | 62   | 60            |
| Smoking during pregnancy (%) | 0 | 9             |
| Yes                  | 0              | 9             |
| No                   | 100            | 91            |
| Number of children at home (%) | 0 | 67            |
| 0                    | 67             | 67            |
| 1+                   | 33             | 33            |
| Age distribution (%) |                |               |
| 20—29                | 41             | 33            |
| 30—39                | 59             | 58            |
| 40—47                | 0              | 9             |
| Ethnicity (%)        |                |               |
| White                | 76             | 74            |
| Other                | 24             | 26            |
| Gestational age (%)  |                |               |
| First trimester      | 6              | –             |
| Second trimester     | 59             | –             |
| Third trimester      | 35             | –             |
| Working full time (%)|                |               |
| Yes                  | 53             | 85            |
| No                   | 47             | 15            |
| Student (%)          |                |               |
| Yes                  | 26             | 27            |
| No                   | 74             | 73            |
| Principal type of water consumed at home (%) | 9 | 21 |
| No water consumption | 9              | 21            |
| Tap water            | 53             | 49            |
| Bottled water        | 24             | 9             |
| Filtered water       | 15             | 21            |
| Source of household water (%) | 82 | 82 |
| Municipal water supply | 82            | 82            |
| Well or spring water  | 18             | 18            |

*One male did not complete the water diary.

**Table 2. Summary of participants' daily water intake (liters)**

|                      | Number | Mean ± SD 10 | 25 | 50 | 75 | 90 |
|----------------------|--------|--------------|----|----|----|----|
| Daily intakes of total water |        |              |    |    |    |    |
| Women                | 34     | 1.86 ± 0.73  | 1.17| 1.45| 1.75| 2.08| 2.33|
| Men                  | 33     | 1.68 ± 0.70  | 0.70| 1.34| 1.59| 2.08| 2.39|
| Daily intakes of tap water |        |              |    |    |    |    |
| Women                | 34     | 0.78 ± 0.51  | 0.20| 0.43| 0.62| 1.12| 1.39|
| Men                  | 33     | 0.78 ± 0.51  | 0.25| 0.34| 0.81| 1.10| 1.23|
| Daily intakes of cold tap water at home | 34 | 0.37 ± 0.40 | 0.02| 0.26| 0.55| 0.97|
| Without shower       | 8      | 0.28 ± 0.30  | 0.04| 0.15| 0.53| 0.60|
| Employed part-time   | 16     | 0.47 ± 0.48  | 0.01| 0.42| 0.73| 1.04|
| or less              |        |              |    |    |    |    |
| All men              | 33     | 0.29 ± 0.35  | 0  | 0  | 0.15| 0.51| 0.69|

*Filtered tap water excluded.

**Table 3. Average daily tap water consumption (liters) by location, temperature and beverage type**

|                      | All women (n = 34) | Women employed full time (n = 18) | Women employed part-time or less (n = 16) | All men (n = 33) |
|----------------------|--------------------|----------------------------------|------------------------------------------|-----------------|
| Consumption at home  |                    |                                  |                                          |                 |
| Cold drinking water  | 0.25               | 0.18                             | 0.34                                     | 0.19            |
| Cold tap water-based beverages | 0.11             | 0.10                             | 0.13                                     | 0.10            |
| Total home consumption of cold tap water | 0.37          | 0.28                             | 0.47                                     | 0.29            |
| Hot tap water        | 0.15               | 0.11                             | 0.20                                     | 0.14            |
| Total home consumption of tap water | 0.52        | 0.38                             | 0.67                                     | 0.43            |
| Consumption outside the home |       |                                  |                                          |                 |
| Cold drinking water  | 0.15               | 0.18                             | 0.11                                     | 0.16            |
| Cold tap water-based beverages | 0.04         | 0.06                             | 0.02                                     | 0.03            |
| Total cold tap water consumed outside the home | 0.19  | 0.23                             | 0.14                                     | 0.18            |
| Hot tap water        | 0.08               | 0.12                             | 0.02                                     | 0.17            |
| Total consumption outside the home | 0.26   | 0.36                             | 0.16                                     | 0.35            |
| Total cold tap water | 0.56               | 0.51                             | 0.61                                     | 0.47            |
| Total hot tap water  | 0.23               | 0.23                             | 0.22                                     | 0.31            |
| Total tap water consumption | 0.78 | 0.74                             | 0.83                                     | 0.78            |

*As reported in the interview.
drinking water intake (Table 5). The Pearson’s and Spearman’s correlation coefficients ranged from 0.52 to 0.78, which are fairly large for exposures assessed in epidemiologic studies (7), but they do indicate some discrepancies between data collection methods. On average, greater beverage consumption and shower duration values, but smaller bathing duration values, were obtained from the interview relative to the diary. However, in each case, the difference between the two estimates was small.

**Discussion**

**Questionnaire and diary assessment methods.** In this study we applied two data collection tools: the questionnaire, intended to report exposures averaged over time, and the prospective water diary, designed to reflect current day-to-day exposure. Questionnaires suffer from potential errors in recall and the inability to report finely detailed information. The quality of data gathered from diary methods depends on the extent to which each participant is willing to measure and record current habits and the representativeness of the days for which the diary is completed (8).

Conducting an interview is logistically preferable to completing diaries because data collection is less burdensome and provides data on exposures averaged over time. As demonstrated in this study, the interview provided essentially the same information as the prospective water diary. Overall mean differences between assessment methods for consumption of drinking water (0.35 l/day), showering (0.7 min/day), and bathing (1.2 min/day) are negligible, and the interview and mean diary record intakes correlate reasonably well. While the 3-day water diary is not necessarily the gold standard, it appears that individuals have the ability to estimate with a fair amount of precision their own true mean values for water intake and for time spent on water-related activities, at least over relatively short periods in the recent past. However, the frequency questionnaire may not perform as well if used to estimate consumption patterns from a more temporally remote time period.

Other limitations of our data for assessing the reliability between diary and questionnaire records were that the questionnaire focused only on home consumption of cold tap water and that the respondents averaged intake levels over working and nonworking days, when consumption habits are expected to differ. Furthermore, the diary did not provide enough information to evaluate effects of weekday or consecutive days. Finally, no direct validation of reported beverage volume, water type, or shower or bathing duration was done for either data collection method.

Our study sample came from an educated and health-conscious population because only women who received prenatal care, who had at least a high-school education, and who volunteered to participate were included in the study. Their water consumption habits differ from the general population because they can probably afford alternatives to tap water and may tend to switch from tap water to bottled or filtered water in order to protect their fetuses’ health. The percentage of individuals who reported bottled or filtered water as the principal type of water consumed at home was higher for women (39%) than for men (30%). Our results are somewhat higher than another study, which reported that 17% of healthy postpartum women consumed mainly bottled water during the first 3 months of their pregnancy (9). On the other hand, an advantage of this educated convenience sample is that they should be more compliant about completing and returning the water diary than a random sample of the general population would be. Consequently, data quality and correlations between the diary and questionnaire may be less favorable in other populations.

**Daily water consumption.** The distribution of daily consumption of total water, tap water, and cold tap water consumed at home is relevant to a wide range of health concerns with drinking water, including waterborne exposure to agents such as fluoride, arsenic, toxic metals, and pesticides, and microbial pathogens such as hepatitis A, cryptosporidia, and Norwalk virus. It is also useful for developing a standard intake distribution so that an individual’s water intake level can be compared to others of the same sex and age (3).

On average, we found that pregnant women and their male partners had similar water consumption intake and that more cold than hot beverages were consumed. Although minor differences in consumption by sex were noted, bigger differences were observed by extent of employment (full time vs. not full time). These data indicate that employment status had a greater influence than sex in shaping individual water consumption habits. It may be that sex was largely a surrogate for working status in another study in which all the men and none of the women were employed outside the home (10).

Although the majority (67%) of all tap water beverages consumed by pregnant women was consumed at home, a significant amount (33%) was consumed either at work, a restaurant, or at a friend’s or relative’s house. Therefore, exposure assessment studies that only take into account water consumption at home or that only take into account levels of tap water contaminants at the residences of study participants would be disregarding approximately one-third of

### Table 4. Showering and bathing habits according to interview

|                     | Female | Male |
|---------------------|--------|------|
|                     | (n = 34)| (n = 33) |
| Participants who shower at least daily (%) | 79 | 94 |
| Average duration of shower (min) ± SD | 11.6 ± 4.0 | 10.4 ± 4.8 |
| Distribution of shower duration (%) | | |
| 5–9 min | 17.9 | 37.5 |
| 10 min | 35.7 | 37.5 |
| 11–30 min | 46.4 | 25.0 |
| Ventilated showers (%) | | |
| During winter season | 43 | 56 |
| During summer season | 61 | 75 |
| Participants who bathe at least daily (%) | 18 | 3 |
| Participants who bathe occasionally (%) | 21 | 3 |
| Average duration of bath (min) ± SD | 22.9 ± 10.1* | 21.3 ± 12.4 |
| Distribution of bath duration (%) | | |
| 8–10 min | 41.7 | 50 |
| 10–20 min | 16.7 | 0 |
| 21–40 min | 41.7 | 50 |

*SD, standard deviation.

### Table 5. Comparison of interview-based questionnaire data with diary results

|                     | Drinking water intake at time (liters/day) | Time spent showering (min/day) | Time spent bathing (min/day) |
|---------------------|-------------------------------------------|-------------------------------|----------------------------|
| Number of participants | 42 | 60b | 60b |
| Mean value (questionnaire) | 0.75 | 10.5 | 2.1 |
| Mean value (diary) | 0.40 | 9.8 | 3.3 |
| Pearson’s correlation coefficient | 0.78 | 0.88 | 0.78 |
| Spearman’s correlation coefficient | 0.75 | 0.63 | 0.52 |
| Mean difference between questionnaire and diary values (CI) | 0.35 (0.21–0.48) | 0.7 (0.5–2.0) | -1.2 (-2.4–0.0) |

CI, 95% confidence interval.

*Twenty-five participants were not included in this analysis because they were not asked about the volume of their water glasses.

Seven participants had missing values.

*Analyses compared individual results obtained from the frequency questionnaire to 3-day averages computed from diary entries.

*Differences were first computed for each participant and then averaged over the study population.
their participants’ total exposure due to tap water consumption.

To our knowledge, the only other study of tap water and total water consumption in pregnant women relied on data from the U.S. Department of Agriculture’s 1977–1978 Nationwide Food Consumption Survey (11). While our results are slightly higher for total water consumption (1.9 l/day vs. 1.6 l/day), we observed lower tap water intake levels than those reported previously (0.78 l/day vs. 1.1 l/day). The small sample size in our study makes it difficult to make any definitive statements; however, this difference may reflect a decline in tap water consumption because the current U.S. population is drinking more bottled and canned beverages than ever before (12).

A substantial proportion of the variation in consumption levels was due to differences between individuals for women working part-time or less (ICC = 0.81), but less so for full-time employed women (ICC = 0.42) and men (ICC = 0.49). These findings suggest that use of a standard water intake level in studies evaluating health effects associated with drinking water contaminants would not be appropriate because it would likely result in attenuated exposure–response relationships and substantial exposure misclassification. These results also indicate that data collection methods for tap water exposure should employ repeated measures over time. Such measures of tap water exposures could be obtained through multiple records of daily water intake or by one-time questionnaires that collect information on tap water exposures integrated over time by the respondent. Similarly, although not the focus of this study, the sources of variation in waterborne contaminant levels would also have to be considered when assessing exposure to drinking water contaminants.

**Assessment of behavioral indicators of tap water exposure.** For assessing total exposure to tap water, it is not appropriate to combine all tap water exposures into one summary estimate because each type of tap water exposure represents a slightly different combination of inhalation, ingestion, and dermal absorption and likely targets different organs (2). We were not able to relate behaviors to biological measures of exposure, so we are unable to directly address contributions from different sources.

Temperature and storage time can affect the type of tap water exposure, especially for volatile tap water contaminants such as trihalomethanes (THMs). For instance, cold drinking water tends to have the highest concentration of THMs because it is usually consumed straight from the tap, and if it is stored, it is stored briefly (average of 1.4 days). Relative to initial tap water levels, hot beverages will have lower THM levels because of volatilization by heating as well as cold beverages stored for extended periods in open containers. We found that all cold beverages prepared at home with tap water were stored for at least 1 day, and most were stored for longer periods (average of 5.1 days) before consumption, thereby permitting equilibrium between the air and water. However, because most of the storage containers were closed (which limits the amount of THM that escapes to the household air), such beverages would still represent a potential source of THM exposure (P. Singer, personal communication). Nonvolatile chlorination by-products and other water contaminants would, of course, remain in the water and be ingested regardless of temperature or storage conditions.

Showering and bathing have been found to be significant sources of THM exposure (2) although the importance of these exposure routes to other water contaminants is not well defined. We found that most people take showers daily and that their showers last an average (± 1 SD) of 10 ± 5 min, so that dermal and inhalation exposure from this activity is substantial on a population level. Although bathing is not a daily activity for the general population, it can represent a significant source of exposure among persons who bathe regularly. Because nearly one-fifth of the women in our study bathed at least daily and an additional 21% bathed occasionally, exposure through this activity should not be ignored, particularly among pregnant women.

**Conclusion**

Studies of the potential health problems associated with tap water have been limited by crude estimates of tap water exposure. The incorporation of a comprehensive assessment of behaviors related to consumption and other uses of water, coupled with improved estimates of levels of tap water contaminants in drinking water, should enhance our ability to evaluate associations between water contaminants and the potential for associated health risks.

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