Consumption of non-public water: Implications for children's caries experience

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Abstract:

There are concerns that the consumption of unfluoridated bottled and tank water may put children at increased risk of developing caries. The aim of this study was to investigate the relationship between non-public water consumption (either from bottles or rainwater tanks) and socio-economic status and both deciduous and permanent caries experience. A random sample of children enrolled in the School Dental Service of South Australia participated in the study (response rate = 71.8%, N = 9,988). Forty-five percent of children had greater than 50% lifetime consumption of non-public water while 36% of children had 0% lifetime consumption. Increased use of non-public water occurred for children from lower socio-economic groups, two-parent families and children from non-metropolitan areas, with these results most likely a result of the residential location of the children. Multivariate modelling revealed a significant positive relationship between deciduous caries experience and consumption of non-public water, even after controlling for the age and sex of the child, socio-economic status and residential location. This relationship was significant only for those children with 100% lifetime availability of fluoridated water. The effect of consumption of non-public water on permanent caries experience was not significant. It is postulated that these findings may result from the lower caries activity in the permanent dentition of children aged 10–15 and possible dietary confounders. Recommendations are made for the addition of fluoride to bottled water, especially with regard to the oral health of younger children.

Key words: water consumption; caries; children; fluoridated; socioeconomic status

Recently, concerns have been raised over the consumption of both bottled water and water from rainwater tanks. The nature of these concerns are several and reflect varying perspectives. From a public health perspective, the quality of bottled water has been brought into question by studies finding bacteria and other chemicals in some bottled waters that have breached the standards laid down by authorities in a number of countries (1–4), although more recent studies indicate an improvement in this regard (5). Concerns about the safety of drinking water from rainwater tanks revolve around the leaching of lead, lime, or paint substrates into the rainwater run-off, the collection of pollutants in tank water in urban or industrial areas, and the capacity for foreign matter to enter the rainwater tank (6–8). From a dental public health perspective, however, concerns have been voiced for some time about the substitution in the diet of tank or bottled water for fluoridated tap water (9,10). More recently, this sentiment has been reiterated by the Centers for Disease Control and Prevention in the US, which stated that the full benefits of community water fluoridation might not be received by persons substituting unfluoridated bottled water for fluoridated mains water (11). However, while fluoridated bottled water is becoming more common in the United States, with more than 20 companies offering the product in 2002 (12), companies in Australia have been reluctant to produce bottled water with what is considered to be appropriate fluoride concentrations (2).

Although maximum fluoride levels have been set at 1.5 mg/L for public drinking water in Australia (13), no guidelines have been specified for bottled or packaged waters. This is despite the wide spread practice in Australia of adding fluoride to public water supplies. Beginning in 1964 with fluoridation of Hobart, the capital of Tasmania, by 1977 every capital city except one was receiving fluoridated water, and approximately two-thirds of the Australian population were resident in fluoridated areas (14). Numerous studies in the last two decades (15–20) and recent reviews (21–22) provide support for the positive health consequences of the consumption of fluoridated water. The regular ingestion of adequately fluoridated water, currently considered in Australia to be between 0.6 and 1.1 parts per million depending on the locality (23), has been found to lower the prevalence and experience of dental caries. Reductions in caries experience of between 20% and 40% have been commonly reported. For example, looking at lifetime residents of fluoridated Townsville and unfluoridated Brisbane (24), 6 year-old children with 100% lifetime exposure to optimally fluoridated water had a dmfs score 36% lower than children with no exposure to fluoridated water. Twelve year-old DMFS scores were 48% lower for children with 100% lifetime exposure than for children with 0% exposure. These effects remained significant after controlling for sex, tooth-brushing frequency, and household income.

The relevance of the concern over the consumption of bottled and tank waters goes hand-in-hand with the increase in consumption of water from non-public sources. Figures released by the Beverage Marketing Corporation in the US show that bottled water consumption in that country has climbed by almost 10% per year between 1991 and 2001, with over 7% compound annual growth rate predicted to 2005 (25). In Australia in 2001, an estimated 1.2 million households, or 16% of all households in Australia consumed bottled water, with 6.9% of the adult population using bottled water as their main source of drinking water (26). Approximately 840 thousand adults, or 11.4% of Australia's adult population, derived their main source of drinking water from a rainwater tank and this was highest in South Australia where 1 in 3 adults consumed tank water as their main source of drinking water. Although the percentage of adults using tank water increased by only 0.5% between 1994 and 2001, there had been an almost sixfold increase in the percentage of adults consuming bottled water as the primary source of drinking water across the same period.

The reasons behind the increasing popularity of mineral, spring and purified waters are not difficult to identify. One factor is a raised health-consciousness in Australia and it is, perhaps, not surprising that bottled non-carbonated waters are pitched as being a healthy alternative to other beverages, containing no kilojoules, no fat, and no cholesterol. A US study found that 35% of people drinking bottled water were doing so primarily as a substitute for the consumption of other beverages (27). Advertising campaigns promote bottled water ~~as being~~ using terms such as “tasty”, “fresh”, “pure”, and “naturally clean”, and companies claim that their water is “the way nature meant it to be”. As such, bottled waters are not only seen as a healthy alternative to alcoholic or sweetened beverages but are increasingly seen as an alternative to tap water as well.

At the same time there exists a poor perception of tap water. In a 2001 survey over a quarter of all Australians adults, or almost 3.6 million people, were not satisfied with the quality of their tap water for drinking, dissatisfaction ranging from 7.8% of people in the Northern Territory and Australian Capital Territory to 42.2% of people in South Australia (21). Of those people who reported being dissatisfied with their water quality, the main problems identified were taste and chlorine, reported by 51.7% and 32.3% of people respectively. Perceptions of differences in the taste of bottled waters versus tap water prevail despite tap water often performing well in blind comparative tastings (28).

In Australia the use of domestic rainwater tanks has had a long history. Australia has a generally hot, dry climate and water is therefore widely perceived as a valuable commodity. Certainly, in rural areas, historical problems with connections to mains water and inadequacies with bore water have led to rainwater tanks becoming widely adopted. However, in states such as South Australia, which receives less rainfall than any other state or territory in the country, the prevalence of rainwater tanks in towns and cities is also high. A survey conducted in South Australia in 1996 showed that while 82% of the rural population used rainwater as their primary source of water for drinking, 28% of the population in metropolitan Adelaide, the capital city, also used water from rainwater tanks (29). The South Australian government encourages the installation of rainwater tanks throughout the state as a result of perceived problems with the quantity and quality of reticulated water supplies (30).

Both bottled and tank water have been promoted as healthy alternatives to other beverages. Complimenting this appeal to health consciousness are concerns over the safety of public water supplies. Contamination by bacteria, viruses, blue-green algae, lead, nitrates and synthetic organic chemicals such as pesticides and herbicides are perennial troubles for public water supplies. Such concerns are highlighted by events such as the outbreak of cryptosporidiosis in Milwaukee, Wisconsin in 1993 where over 400,000 persons were affected by the disease (31), resulting in the death of an estimated 100 people (32). In Australia, the protozoa Giardia and Cryptosporidium were detected in the drinking water supply of Sydney, New South Wales in 1998 (33) leading to widespread concern over the quality of public water supplies. At the peak of the scare, sales of bottled waters had increased by 330% over the same period the previous year (34). Families with younger children were the most likely to be purchasing bottled water for the first time. The impact of the scare in Australia is demonstrated by figures released three years later by the Australian Bureau of Statistics which found that in 2001, 25.4% of those people dissatisfied with mains water in New South Wales attributed this to concerns regarding microbial and algae contamination, compared to between 4.6% and 12.2% in Australia's other states and territories (26).

All these factors indicate that the consumption of bottled and tank waters is not merely a temporary fad. Consumption of non-public water is increasingly coming to replace mostly fluoridated tap water as the drinking water of choice. This is reflected in the continuing decline in the percentage of adults using mains/town water as their main source of drinking water and the increase in the percentage of adults using bottled water (26). Although it appears intuitively likely that a decrease in consumption of fluoridated water accompanying the use of bottled or tank water may lead to an increase in caries, literature searches fail to identify previous studies that have investigated this matter. The current study, therefore, sought to describe the relationship between consumption of non-public water and dental caries experience among South Australian children with varying levels of lifetime availability of optimally fluoridated water. It was hypothesised that the relationship between non-public water consumption and caries would only be significant for children living continuously in fluoridated areas. Additionally, the influence of socioeconomic status (SES) on bottled and tank water consumption was investigated. Although 95.4% of South Australians had access to mains water in 1994 and therefore almost all families have the choice of using public water (26), it was predicted that children from lower socio-economic status families would have higher use of non-public water than children from higher socio-economic status families.

Method

This study reports on cross-sectional results from the baseline component of a longitudinal study of caries experience in South Australian children conducted between 1991 and 1995. Despite the age of the data set, the data still represent a rare opportunity to investigate this increasingly important oral health issue due to the paucity of scientific data related to the relationship between the consumption of non-public water and caries experience.

Participants

This study sampled children from fluoridated and non-fluoridated metropolitan and rural areas of South Australia. Children attending the South Australian School Dental Service for a periodic dental examination between June 1991 and May 1992 were randomly sampled on the basis of birth date, the sampling frame varying by the fluoridation status of the region in which a patient lived. The School Dental Service provides routine dental care to children whose parents consent to their enrolment in the service. Routine dental care involved regular examinations occurring approximately yearly at the time of data collection, as well as preventive services, restorations and oral surgery as required. In 1991/92 the Service operated from 85 fixed clinics although a number of mobile clinics were also in operation, mostly in rural areas. Services were provided free of charge to all students up to and including the year in which they turned 18. Participation rates in 1991/92 were 82.2% among preschool and primary school children and 69.6% among secondary school students.

Children were randomly sampled from two strata. One stratum was Adelaide, the state capital, where approximately 1 in 12 patients were selected (those born on the 13th, 30th or 31st day of any month). In 1992 the estimated resident population of 5–15-year-olds in Adelaide was 139,018. The other stratum comprised South Australia rest-of-state, where children were selected if their day of birth fell on the 13th or between the 26th and 31st day inclusive of any month, giving a sampling ratio of approximately 1 in 5. Outside of the capital, South Australia is predominantly non-fluoridated and the population of 5–15-year-olds in 1992 was 61,763. The sampling scheme was adopted to provide for approximately equal numbers of children to be sampled at each stratum and the 5–15-year-old age group was used for these calculations because population figures available from the Australian Bureau of Statistics only provided for specific age range groupings (59, 1014) by Statistical Divisions, not individual age year statistics.

Oral examinations

Data describing caries experience were recorded by either dental therapists or dentists from the School Dental Service during the course of scheduled periodic examinations. In South Australia, dental therapists are qualified to examine and diagnose, and provide restorative, preventive and community dental services for children under the supervision of a dentist. Written instructions were supplied to clinical staff concerning criteria for recording the decayed, missing and filled indices on deciduous (dmfs) and permanent tooth surfaces (DMFS). The instructions made use of visual criteria only within the approach advocated by the World Health Organization (35) with further guidelines for their surface level application from the US NIDR (36). The scoring of decay was based on visual criteria and was recorded if cavitation had occurred and/or the lesion extended into the dentine. All surfaces of teeth missing due to decay were recorded in dmfs and DMFS scores. Information was collected on five surfaces for each molar and premolar tooth and four surfaces for each canine and incisor tooth in the deciduous and permanent dentition. The written guidelines were discussed with the researchers during in-service training and other staff meetings. The large number of examiners and their widespread geographical distribution across South Australia precluded further calibration procedures. However, it should be noted that the dental therapists all operated within the one state and had received training in the one school, leading to an amelioration of possible systematic geographic variations in the application of diagnostic criteria which may have led to biased estimates of caries experience. Moreover, the design aspects employed in this study were deemed consistent with the orientation of the project towards community effectiveness using a practitioner perspective on the diagnosis of disease experience. Nonetheless, reliability studies conducted within the South Australian School Dental Service subsequent to this study demonstrated that examiners reach satisfactory levels of reliability on the observation of caries experience. Between dental therapists, a Kappa statistics of 0.98 was obtained for inter-examiner reliability for DMFT and the inter-examiner reliability between dentists and dental therapists reached 0.87 for DMFT.

Parental questionnaire

At the time of a child's visit to a School Dental Service clinic a questionnaire was given to each sampled student to be delivered to their parent or guardian. Up to two reminder notices were mailed to parents or guardians who did not respond to the questionnaire. Also, an effort was made to obtain missing questionnaire data and correct erroneous information by telephoning the parents or guardians of the participants. Principally, missing or erroneous information regarding residency history and water use (e.g., where dates indicated residencies commencing prior to a child's birth or where years of residency were missing) were sought. Parents were contacted at either their stated address on the questionnaire or through a contact person indicated by the parents on the questionnaire. Up to six attempts were made to telephone the parents and approaches were made at various times of the day. As a result of this process, the percentages of South Australian children with missing water consumption history of two years or greater decreased from 9.1% to 1.2% of the sample.

The parental questionnaire was used to obtain information on lifetime residential history, usual source of drinking water and socioeconomic status. Parents or guardians were asked to specify the location of each residence that their child had lived at for greater than 6 months, the length of time at each residence and the usual source of drinking water at each residence ('Public Supply', 'Tank/Other', or 'Don't Know'). This enabled a calculation of both percent lifetime consumption of non-public water and percent lifetime availability of fluoridated water.

Lifetime consumption of non-public water was calculated by summing, across all residences, time spent at each residence where non-public water was the usual source of drinking water. This was then divided by the child's age to obtain a measure ranging from zero (no consumption of non-public water) to 100% (all of lifetime consumption of non-public water).

Per cent lifetime availability of appropriately fluoridated water was calculated in the following manner. Postcode information supplied by the parents or guardians was matched with an electronic database of fluoride content of water for each postcode within Australia.

This information was derived from a variety of health and water authorities within Australia. For children who had spent time in countries outside Australia, fluoridation status was obtained where necessary from various authorities from those countries or from reported assays of local water content. Due to variations in the precision with which fluoride concentrations were specified, fluoride content was categorised as being negligible or 0 ppm (less than 0.3 ppm F), sub-optimal or 0.5 ppm (0.3 to 0.7 ppm F), or optimal or 1 ppm (greater than 0.7 ppm F). For each residence the time spent at that residence was multiplied by the categorised fluoride content of the public water supply for that area. Availability of fluoridated tap water was summed across each residential location to obtain the measure of per cent lifetime availability of appropriately fluoridated water. The percent could range from zero (no availability) to 100 (all of lifetime availability of 1.0 ppm F). No assumption is made in this measure of the actual consumption of fluoridated tap water, only its availability, and this should be differentiated from calculations of percent lifetime exposure to fluoridated water as described in earlier research (15). Cases with more than two years missing fluoride access data were not included in the analysis.

Socioeconomic status was assessed by both the highest level of education completed by either parent and total family income before tax. Annual pre-tax income was reported using 10 groupings which for this analysis were collapsed into five categories: up to $20,000; $20,001–$30,000; $30,001–$40,000; $40,001–$50,000; and over $50,000. Education was assessed for each parent using six groupings. For this study, highest level of education attained by either the female or male parent or guardian was collapsed into four categories by combining the lowest educational attainment responses. Categories were: not completed secondary school; completed secondary school; some university or college; and completed university or college. Occupational prestige, an indicator measure of social class, was measured using the Daniel Scale (37). Occupational prestige was coded into five categories:

12–27 (highest occupational prestige), 28–41, 42–55, 56–69 (lowest occupational prestige) and 'No Usual Occupation'. An aspect of family structure was also used in the analyses, with children recorded as being from either single-parent families or not.

Residential location was measured using the Rural, Remote and Metropolitan Areas classification (RRMA), an index of remoteness developed by the Australian Department of Primary Industries and Energy and the Department of Human Services and Health (1994). The RRMA describes six levels of remoteness, however for the purpose of analyses here they were collapsed into three categories: metropolitan, rural and remote.

Analysis

The dmfs (deciduous dentition) and DMFS (permanent dentition) indices, which represent the number of decayed, missing or filled tooth surfaces per child, were the principal outcome variables in this investigation. The mean dmfs index was analysed only for children aged between 4 and 9 years old while the mean DMFS index was analysed only for children aged between the ages of 10 and 15 years old. The primary explanatory variable was percent equivalent of lifetime consumption of non-public water.

For descriptive purposes, age-specific per cent lifetime use of non-public water is presented graphically for the two extreme values of consumption of non-public water (0% and 100%) and for two intermediate consumption levels: 1–50% and 51–99%. Although this creates non-equivalent intervals of non-public water consumption, the purpose of this categorization was to use the polar extreme groups of 0% and 100% consumption while still allowing comparison of various ranges among children with two intermediate levels of exposure.

Descriptive statistics are presented for both mean caries experience indices and percent lifetime consumption of non-public water by the socio-economic variables of highest parental education, gross household income, occupational prestige, single-parent status and residential location. Statistics are presented for both children aged 4–9 and those aged 10–15. In addition, the bivariate association between each independent and dependent variable was explored using general linear modelling analysis of variance.

Multivariate modelling was performed using the UNIANOVA procedure in SPSS 11.0 for Windows. This analytic procedure provides regression analysis and analysis of variance for one dependent variable by one or more factors and/or covariates. The partitioning of the sum-of-squares of each effect utilized the sum of squares adjusted for any other effects that did not contain it, and orthogonal to any effects that contained it. For each model percent lifetime consumption of non-public water was used as the chief explanatory variable and was used as a categorical variable. Other categorical variables included in the modelling were sex, income, education, occupational prestige, family type and residential location. Age was entered as a continuous variable.

Multivariate models were constructed for three different conditions: 0% lifetime availability of fluoridated tap water, 100% lifetime availability of fluoridated tap water, and intermediate availability (1–99%) of fluoridated tap water. The intention of running models under the three different conditions was to circumvent the problem of comparing children with and without consumption of non-fluoridated bottled and tank water even in areas where there is no fluoridated water available in any event. In this circumstance, the substitution of bottled or tank water for public water has no effect on the exposure to fluoridated tap or mains water. However, where children have spent their entire lives at a residence with access to fluoridated tap water, it might be expected that in this case a higher percentage intake of non-public water would lead to a greater reduction in exposure to fluoridated water compared to children who consumed little or no non-public water.

Results

A total of 13,911 children were sampled with data obtained on 9,988 children aged 3–18 years old (response rate = 71.8%). Because very small numbers of children were aged less than 4 or greater than 15, children from these ages were excluded from the analyses. Results have been presented for two age groups. Children aged 4–9 (n = 5,129) were used for analyses of deciduous dentition, while children aged 10–15 (n = 4,803) were used for analyses of permanent dentition.

Lifetime consumption of non-public water by age group is shown in Figure 1. From the age of five there was little variation in water consumption across age groups. Overall, 36% of children had 0% lifetime consumption while 45% of children had greater than 50% lifetime consumption. This compares well with statistics from 1994 showing that 36.7% of South Australian people were reported as using tank water as their main source of drinking water and 7.9% of people reportedly consumed bottled water as their main source of drinking water (21). The results for 4-year-olds can be considered unreliable due to the small number of these children in the sample (n = 22). It should be noted that all subsequent analyses were conducted both with and without 4-year-old children however the results varied little as a result of their exclusion. Therefore all results for the deciduous dentition are presented with the inclusion of 4-year-old children.

Mean dmfs and DMFS scores by demographic and socio-economic variables are shown in Table 1. For both the deciduous and permanent dentition caries experience scores decreased with increasing parental education. Mean dmfs scores were 81.8% and 48.6% higher in the deciduous and permanent dentition respectively for children whose parents had not completed secondary school compared to children whose parents had completed university or college. A similar effect was born out for household income, with children from the families with the lowest household income having 52.9% and 68.3% higher mean caries scores in their deciduous and permanent dentitions respectively than children from families with incomes over $50,000 per year. The socio-economic differentials were even more marked with relation to occupational prestige. Children whose parents had no usual occupation had 137.9% and 115.6% higher caries experience in the deciduous and permanent dentitions respectively, than did children with at least one parent with the highest occupational prestige scores, between 12 and 27 on the Daniel Score. The differences in caries experience by single-parent status were not as appreciable as for the other socio-economic variables, and for children aged 4–9 was not statistically significant. However, mean DMFS among 10–15-year-old children was 24.4% higher for those children living within a single-parent family compared to children not in a single-parent family and this was statistically significant. Caries experience also varied according to geographic location although this was only statistically significant among 4–9-year-olds in the deciduous dentition, where children living in rural or remote areas had 68.9% and 111.4% higher caries experience respectively than children living in metropolitan Adelaide.

Differences in consumption of non-public tank and bottled waters by socioeconomic status are shown in Table 2, with results again presented for both 4–9-year-old children and 10–15-year-old children. Using the highest level of education completed by either parent, the relationship with non-public water consumption was most clear for the older children, where lower educational attainment was related to increased exposure to non-public water. The relationship between SES and water consumption was more apparent for taxable family income, where there was a significant decline in lifetime consumption of non-public water across income groups for both the younger and older children. Similarly, children of parents with the highest occupational prestige (lowest scores) had consumed less non-public water across their lives. However, there was a trend for an increase in consumption of non-public water with higher occupational prestige up to the second highest category (Daniel Score = 28–41). Single-parent status was also related to consumption; children in single parent families were found to have lower lifetime consumption of non-public water than children in two-parent families. This was despite the lower socio-economic status of parents in a single-parent family. Finally, children from metropolitan areas consumed considerably less non-public water than did children in rural and remote locations.

There was a strong and consistent relationship between consumption of bottled or tank water and caries experience in the deciduous dentition (Table 3). Male and female children who had consumed non-public water as their main source of drinking water for their entire life had a mean dmfs score 47.9% and 57.1% higher respectively than children who had never consumed tank or bottled water as their main source of drinking water. However, the pattern is less clear in the permanent dentition, where differences across groups for males were minimal and the overall means appeared to be driven by results for females who had a mean DMFS score 11.3% higher for children with 100% lifetime consumption of non-public water than for children with 0% consumption of non-public water.

To test the significance of the apparent relationship between caries experience and consumption of either tank or bottled water, a series of general linear models were computed using deciduous dmfs and permanent DMFS scores as the dependent variables. To control for variations in the availability of fluoridated tap water, the models were run under three conditions: no lifetime availability of fluoridated tap water, some lifetime availability of fluoridated tap water (between 1 and 99%), and 100% lifetime availability of fluoridated tap water. The distributions of socio-economic variables and percent lifetime consumption of non-public water across these conditions are shown in Table 4. The relationships were similar in both the deciduous and permanent dentitions. Not surprisingly, the consumption of non-public water was greatest where the availability of fluoridated tap water was least. Also consistent with expectations, residential location was strongly related to availability of fluoridated tap water, with children from rural areas more likely to have no availability of fluoridated tap water than 100% lifetime availability. All SES variables were also significantly related to percent lifetime availability of fluoridated tap water, with lower SES being related to lower lifetime availability and higher SES being characterised by increased availability of fluoridated tap water. The exception to this was single-parent status, with children from a single-parent household more likely to have had increased availability of fluoridated tap water than were children not from a single-parent household.

Two models were evaluated under each category of access to fluoridated water. The first looked at the relationship between lifetime consumption of non-public water and caries experience after controlling for the demographic variables of age and sex. The second model again examined the relationship between consumption of non-public water and caries experience, this time controlling for the demographic variables of age and sex, the socio-demographic variables of family income, parental education, occupational prestige, family type (assessed by single-parent status), residential location, and the potentially confounding fluoride exposure sources of fluoridated toothpaste (assessed by frequency of tooth brushing with fluoridated toothpaste) and fluoride tablets (assessed by whether or not children had at any time consumed fluoride tablets or drops).

Looking at the deciduous dentition, in the first model, per cent lifetime consumption of non-public water was entered with age and sex as covariates for children who had had no access to fluoridated water across their lifetime (see Table 5). The relationship between consumption of non-public water and dmfs scores was not significant, $p>.05$. In the second model per cent lifetime consumption of non-public water was entered with age, sex, family income, parental education, occupational prestige, family type, residential location, frequency of brushing with fluoridated toothpaste and fluoride tablet use. Again, the relationship between consumption of non-public water and caries experience was not significant. Similar results were apparent for both models under the second condition, mixed lifetime access to fluoridated water. Again, in both models the relationship between consumption of non-public water and dmfs was not significant. However, under the third condition, children who had spent their entire life in localities with fluoridated water available, the relationship between consumption of non-public water and dmfs scores was significant after controlling for age and sex. Indeed, after controlling for age, sex, income, education, occupational prestige, family type, residential location, frequency of brushing with fluoridated toothpaste and fluoride tablet use the association between caries experience and percent lifetime consumption of non-public water remained significant, although the effect size (measured using partial eta-squared) of this relationship was small ($\eta^2 = 0.01$).

Running the same series of models, this time using the permanent DMFS scores as the dependent variable (see Table 6), it can be seen that the effect of consumption of non-public water on caries experience was not significant for either of the models under any of the three conditions of access to fluoridated tap water.

Although the multivariate models control for residential location, due to the possible confounding of the relationship between socio-economic status and consumption of non-public water with residential location, the models were also run using only those children living in metropolitan areas. No differences were found in the outcome of the results and these results are therefore not presented here.

Discussion

This study found that children of lower socio-economic status were more likely to consume non-public water. Deciduous caries experience was highest for children with the greatest lifetime consumption of tank and bottled water. For children who had lifetime availability of fluoridated tap water, the effect of consumption of non-public water was significant even after controlling for family income, residential location, age, sex and exposure to discretionary fluorides such as fluoridated toothpaste and fluoride tablets.

Although children from lower socio-economic backgrounds were found to be more likely to consume non-public water it is quite possible that this result was confounded with residential location. Children aged between 4 and 9, for example, living in rural locations had a mean lifetime consumption of non-public water of 71%, compared to only 25% for children living in metropolitan areas. Indeed, looking across income categories, the ratio of metropolitan to rural and remote children was 1:1.56 in the lowest income group (up to $20,000) yet 1:0.56 in the highest income group (more than $50,000), and within residential location consumption of non-public water did not vary appreciably across income categories. A similar confounding most likely explains the unexpected relationship between family structure and consumption of non-public water, where children of one-parent families were found to consume less non-public water than two-parent families. The ratio of metropolitan to rural and remote children was 1:1.08 in one-parent households and 1:0.92 in two-parent households.

The significant effect for consumption of non-public water on deciduous caries experience is consistent with the idea that children are substituting bottled or tank water for fluoridated tap water. In this case, the higher experience of caries would be seen as resulting from the decreased exposure to fluoride obtained from tap water. It makes intuitive sense therefore that non-public water consumption does not have a significant effect for children who have had either no access or intermediate access to fluoridated tap water. It makes little difference to children living in non-fluoridated localities whether they consume non-fluoridated tap water or non-fluoridated bottle or tank water in terms of fluoride consumption.

The results also show that the explanation for the significant effect of non-public water consumption is not due to differences in income or other socio-economic variables between the water consumption groups. After controlling for socio-economic characteristics, the effect of consumption of non-public water on caries experience in the deciduous dentition remained significant.

A less unexpected result of this study, given the findings for the deciduous dentition, was the lack of a significant relationship between consumption of non-public water and caries experience in the permanent dentition across any of the differing conditions of access to fluoridated tap water. Earlier research using these data on South Australian children had noted the small absolute mean number of permanent tooth surfaces upon which caries was prevented by exposure to fluoridated water supplies. The benefit was considerably less than noted for the deciduous dentition, and was smaller in South Australia than another comparison state, Queensland. Slade et al. suggested that these results reflected the lower caries experience of children in their permanent dentition, the possible impact of fissure sealants and the possible operation of a halo effect in South Australia (15). Although the halo effect would be expected to pertain to deciduous as well as to permanent teeth, the lower caries experience in permanent teeth may make the halo effect more of a problem in obtaining significant results in the permanent dentition than in the deciduous dentition. Against this background it was not unexpected that the association for exposure to non-public water was not strong, or statistically significant, for the permanent dentition. Another possible explanation for this is that children with higher lifetime consumption of tank or bottled water are substituting the drinking of non-public water for the drinking of soft drinks, effectively counter-balancing the reduced caries prevention of non-public water with a reduced consumption of caries promoting soft drinks. In the Australian population there is a noticeable increase between the ages of 4 and 15 in both the total consumption of soft drinks (128.9

average gms/person increasing to 525.4 average gms/person) and consumption of soft drinks as a percentage of total non-alcoholic beverages (15.0% increasing to 34.4%) (38). It may be that those children consuming bottled water at older ages are substituting water for the generally high consumption of soft drinks of their peers. However, because dietary intake was not assessed in the current study, this possibility could not be investigated. Further explanation of how non-public water is consumed and its potential substitution for either fluoridated tap water or sugary, acidic soft drinks and other beverages by age would be highly desirable.

The differential effect between the deciduous and permanent dentitions might be explained in a number of ways. Caries activity is greater in the deciduous dentition. For instance at approximately the same interval after the first deciduous and permanent teeth erupt, i.e. at ages 6 and 12 years, the mean deciduous caries experience is 1.51 while for the permanent teeth it is 0.83 (39). Any association with permanent caries experience will be more difficult to observe. Cumulative caries experience might be greater in the deciduous teeth because of differences in the timing and/or incorporation of fluoride in developing enamel, tooth morphology, risk behaviours across the early life-course or the impact of home or professional preventive measures like brushing with toothpaste, or application of fissure sealants.

The use of an existing data set for this study created a number of limitations that could be considered in conducting research specifically planned to study non-tap water consumption. In general, such research would seem best conducted only in areas with availability of fluoridated water. Resources would then be put to their most productive use in maximising participation and thereby representativeness, increasing reliability of both measures of water consumption and caries experience.

It should be noted that, as discussed here, the drinking of bottled or tank water is neither immediately deleterious nor beneficial to oral health in and of itself. The consumption of non-public water is associated with a number of other factors and it is these that impact upon the progression of dental disease. Such factors include diet and exposure to fluoride. There is a need for recognition, therefore, that when children are consuming non-public water they are also consuming non-fluoridated water. Although this may be more beneficial than the consumption of high sugar and/or acidity beverages, it is less beneficial, from an oral health perspective, than the consumption of fluoridated water.

It should also be noted that this study could not differentiate between people consuming water from rainwater tanks and those drinking bottled water. However, it is likely that non-public water consumption, especially in rural areas, is principally comprised of rainwater consumption. There appears to be a need for more information to be circulated concerning the consumption of water from rainwater tanks. Across Australia, rainwater tanks provide the main source of drinking water for 11.4% of the population, with this being 33.1% in South Australia (26). Considering that children with 100% lifetime consumption of non-public water had 52.7% higher deciduous caries scores than children with 0% lifetime consumption of non-public water, it is important that an effort be made to remedy the present situation. Efforts could be directed at either reducing the use of tank water for domestic drinking water consumption or further encouraging the appropriate use of fluoride to compensate for the lack of fluoride in the drinking water. Given the higher percentage of children in rural or remote areas using non-tap water and the higher caries experience of lower socio-economic status households such efforts should be both geographically and individually targeted. Although fluoride tablets have been suggested for those people using rainwater only for drinking (30), this regimen has not been widely adopted. Only in circumstances of established high risk to caries would the use of fluoride tablets under dental advice as an individual preventive measure be encouraged. Alternatively, emphasis could be given to increased frequency of toothbrushing with fluoridated toothpaste among children with little or no exposure to fluoridated tap water.

It is also time that bottled water manufacturers in Australia began marketing fluoridated water. In the US more than 20 companies produce water with optimum fluoride concentrations. This is becoming increasingly important as consumption of tap water decreases and bottled water's share of all consumed drinks increases (25). Between 1998 and 2001 there was a further increase in the percentage of Australians consuming bottled water as their main source of drinking water, from 5.1% to 6.9% (26). However, consumers currently have little choice in Australia and the imminent introduction of fluoride-containing bottled water does not look likely. The Australian Chapter of the International Bottled Water Association proposes that one reason why people are drinking bottled water is actually to avoid chemicals such as fluoride used in the treatment of public water supplies (40). Bottled water is promoted as a healthy, chemical-free alternative. There is a need for bottled water manufacturers to take a stand on the issue of the benefits of appropriately fluoridated water and provide consumers with choice.

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Figure 1. Per cent lifetime use of non-public water by age

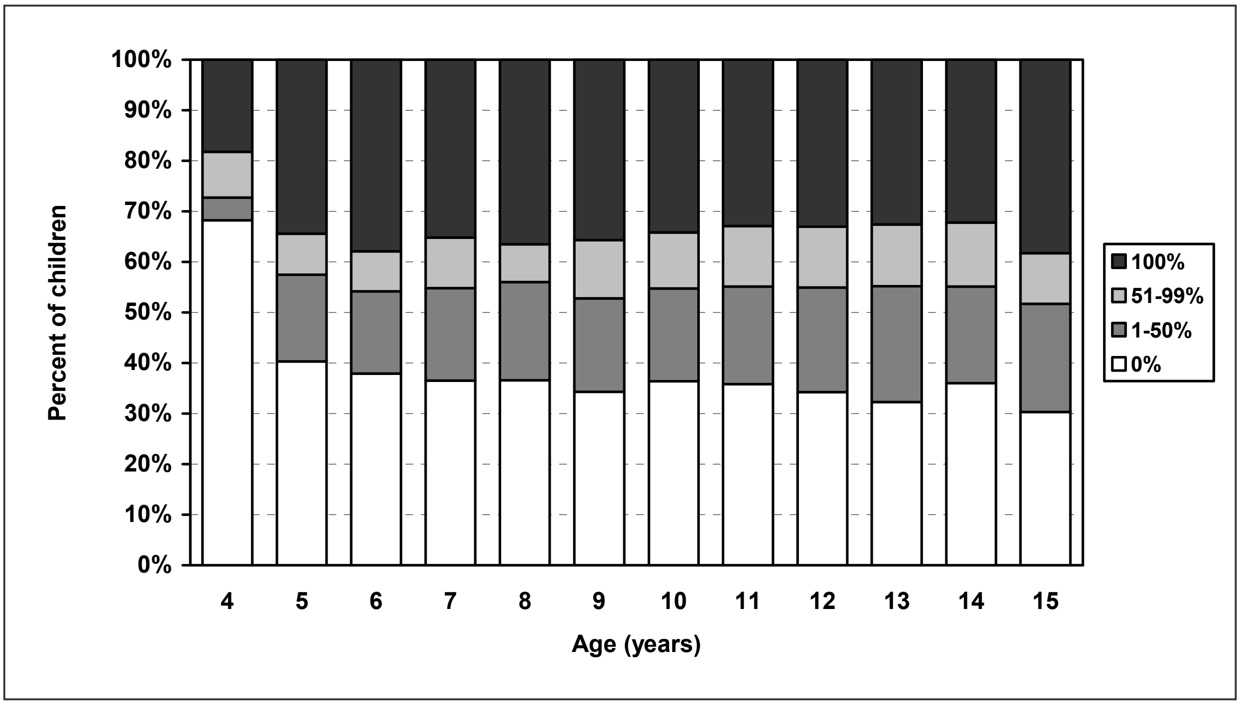

Table 1. Mean dmfs and DMFS scores by socio-economic characteristics

	Children aged 4–9			Children aged 10–15		
Socio-economic Variables	*n*	Mean dmfs	95% CI	*n*	Mean DMFS	95% CI
Highest Education						
Not compl. secondary	1,383	4.40	4.04 – 4.75	1,526	1.62	1.49 – 1.75
Compl. secondary	1,875	3.61	3.35 – 3.88	1,582	1.34	1.22 – 1.46
Some uni/college	538	3.46	2.98 – 3.94	458	1.26	1.03 – 1.49
Compl. uni/college	1,058	2.42	2.14 – 2.71	972	1.09	0.97 – 1.22
	F (3,4950) = 22.63, $p < .001$			F (3,4534) = 10.21, $p < .001$		
Household Income						
Up to $20,000	1,297	4.22	3.87 – 4.57	1,144	1.70	1.52 – 1.88
$20,001 to $30,000	1,212	4.07	3.70 – 4.45	1,022	1.39	1.26 – 1.52
$30,001 to $40,000	991	3.17	2.86 – 3.47	901	1.29	1.15 – 1.44
$40,001 to $50,000	525	2.61	2.20 – 3.02	510	1.14	0.97 – 1.31
Over $50,000	590	2.76	2.32 – 3.19	639	1.01	0.88 – 1.15
	F (4,4610) = 13.54, $p < .001$			F (4,4211) = 10.49, $p < .001$		
Occupational Prestige						
No Usual Occupation	109	5.21	4.00 – 6.42	110	2.07	1.43 – 2.71
56–69 Daniel Score (lowest)	844	4.53	4.07 – 4.99	711	1.59	1.38– 1.80
42–55 Daniel Score	1,655	3.38	3.11 – 3.65	1,537	1.43	1.31 – 1.55
28–41 Daniel Score	1,873	3.33	3.07 – 3.59	1,809	1.27	1.16 – 1.37
12–27 Daniel Score (highest)	298	2.19	1.74 – 2.65	284	0.96	0.75 – 1.17
	F (4,4774) = 13.16, $p < .001$			F (4,4446) = 7.06, $p < .001$		
Single-parent Family						
Yes	629	3.92	3.42 – 4.42	654	1.68	1.48 – 1.88
No	4,340	3.53	3.36 – 3.71	4,010	1.35	1.27 – 1.42
	F (1,4967) = 2.35, $p = .125$			F (1,4662) = 10.60, $p = .001$		
Residential Location						
Metropolitan	2,417	2.64	2.45 – 2.83	2178	1.33	1.24 – 1.42
Rural	2,519	4.46	4.20 – 4.72	2437	1.45	1.35 – 1.56
Remote	50	5.58	3.62 – 7.54	62	1.47	0.86 – 2.08
	F (2,4983) = 62.48, $p < .001$			F (2,4674) = 1.54, $p = .214$		

Table 2. Percentage lifetime consumption of non-public water by socio-economic characteristics

	Children aged 4–9			Children aged 10–15		
Socio-economic Variables	*n*	Mean	95% CI	*n*	Mean	95% CI
Highest Education						
Not compl. secondary	1,427	48.43	46.11 – 50.74	1,562	51.55	49.36 – 53.74
Compl. secondary	1,923	50.72	48.71 – 52.72	1,624	50.66	48.52 – 52.81
Some uni/college	550	44.83	41.20 – 48.47	467	42.66	38.85 – 46.47
Compl. uni/college	1,089	48.07	47.61 – 50.07	1,001	46.02	43.39 – 48.65
	F (3,4985) = 2.79, p = .039			F (3,4650) = 7.43, p < .001		
Household Income						
Up to $20,000	1,337	50.63	48.28 – 52.98	1,175	49.49	47.02 – 51.97
$20,001 to $30,000	1,246	51.76	49.28 – 54.23	1,046	52.34	49.69 – 55.00
$30,001 to $40,000	1,016	47.61	44.87 – 50.35	927	49.21	46.38 – 52.04
$40,001 to $50,000	539	48.06	44.27 – 51.84	530	46.08	42.31 – 49.86
Over $50,000	603	40.33	36.91 – 43.75	649	42.43	39.17 – 45.69
	F (4,4736) = 7.74, p < .001			F (4,4322) = 5.81, p < .001		
Occupational Prestige						
No Usual Occupation	112	44.79	36.54 – 53.04	110	39.36	31.63 – 47.08
56–69 Daniel Score (lowest)	862	46.87	43.95 – 49.80	726	46.78	43.59 – 49.96
42–55 Daniel Score	1,707	47.69	45.59 – 49.80	1,574	46.81	44.65 – 48.97
28–41 Daniel Score	1,927	53.31	51.31 – 55.31	1,862	55.00	53.02 – 56.97
12–27 Daniel Score (highest)	304	36.85	32.29 – 41.41	291	37.00	32.41 – 41.60
	F (4,4907) = 11.46, p < .001			F (4,4558) = 17.30, p < .001		
Single-parent Family						
Yes	646	39.52	36.31 – 42.74	675	40.28	37.13 – 43.43
No	4,460	50.20	48.89 – 51.51	4,108	50.34	49.00 – 51.68
	F (1,5104) = 32.88, p < .001			F (1,4781) = 31.09, p < .001		
Residential Location						
Metropolitan	2,483	24.84	23.41 – 26.28	2,240	25.27	23.79 – 26.75
Rural	2,580	71.07	69.56 – 72.58	2,485	69.33	67.79 – 70.88
Remote	60	85.46	78.26 – 92.66	71	79.61	71.99 – 87.25
	F (2,5120) = 976.60, p < .001			F (2,4793) = 836.15, p < .001		

Table 3. Deciduous (4–9-year-old) and permanent (10–15-year-old) caries experience by consumption of non-public water

	Male		Female		Total	
	Number	Mean (SD)	Number	Mean (SD)	Number	Mean (SD)
4–9-year-old dmfs						
0%	954	3.25 (6.01)	900	2.63 (4.75)	1,854	2.95 (5.45)
1–50%	482	3.64 (5.90)	412	2.66 (4.78)	894	3.19 (5.43)
51–99%	239	3.62 (5.78)	208	3.31 (5.96)	447	3.48 (5.86)
100%	940	4.82 (6.85)	850	4.09 (6.23)	1,790	4.47 (6.57)
10–15-year-old DMFS						
0%	779	1.38 (2.37)	830	1.33 (2.19)	1,609	1.35 (2.28)
1–50%	473	1.32 (2.23)	471	1.39 (2.52)	944	1.35 (2.38)
51–99%	289	1.37 (2.45)	261	1.63 (3.51)	550	1.49 (3.00)
100%	793	1.38 (2.24)	781	1.48 (2.53)	1,574	1.43 (2.39)

Table 4. Non-public water use and SES characteristics by availability of fluoridated tap water

	Lifetime availability of fluoridated tap water					
	Children aged 4–9			Children aged 10–15		
	0% (*n*=754)	1-99% (*n*=1,722)	100% (*n*=2,653)	0% (*n*=672)	1-99% (*n*=1,925)	100% (*n*=2,206)
	%	%	%	%	%	%
% lifetime non-public water use	*(n=754)*	*(n=1,717)*	*(n=2,653)*	*(n=672)*	*(n=1,921)*	*(n=2,206)*
0%	18.3	22.1	52.3	17.3	22.4	50.4
1–50%	6.0	24.5	17.0	6.4	25.3	19.8
51–99%	4.2	16.4	5.6	5.1	20.5	6.1
100%	71.5	37.0	25.0	71.3	31.8	23.7
	χ^2 (6) = 953.97, $p < .001$			χ^2 (6) = 949.65, $p < .001$		
Highest Education	*(n=734)*	*(n=1,671)*	*(n=2,585)*	*(n=653)*	*(n=1,867)*	*(n=2,135)*
Not compl. secondary	33.2	29.3	26.9	39.5	32.7	32.6
Compl. secondary	42.4	38.9	37.2	38.6	34.5	34.1
Some uni/college	7.1	10.7	12.4	5.2	10.9	10.8
Compl. uni/college	17.3	21.2	23.5	16.7	22.0	22.6
	χ^2 (6) = 37.92, $p < .001$			χ^2 (6) = 36.99, $p < .001$		
Household Income	*(n=688)*	*(n=1,600)*	*(n=2,454)*	*(n=586)*	*(n=1,747)*	*(n=1,995)*
Up to $20,000	32.4	31.6	24.9	31.1	30.7	22.9
$20,001 to $30,000	33.0	24.2	25.8	30.9	21.9	24.2
$30,001 to $40,000	18.8	21.5	22.1	20.0	22.5	20.9
$40,001 to $50,000	8.3	10.4	12.9	8.0	10.6	14.9
Over $50,000	7.6	12.4	14.4	10.1	14.3	17.1
	χ^2 (8) = 70.02, $p < .001$			χ^2 (8) = 80.88, $p < .001$		
Occupational Prestige	*(n=724)*	*(n=1,639)*	*(n=2,550)*	*(n=644)*	*(n=1,833)*	*(n=2,087)*
No Usual Occupation	2.2	3.4	1.6	1.2	3.4	1.9
56–69 Daniel Score (lowest)	18.8	18.9	16.4	16.1	17.3	14.6
42–55 Daniel Score	33.4	24.3	35.4	32.8	34.1	35.4
28–41 Daniel Score	42.5	35.9	40.4	46.7	37.8	41.6
12–27 Daniel Score (highest)	3.0	7.6	6.2	3.1	7.3	6.6
	χ^2 (8) = 44.21, $p < .001$			χ^2 (8) = 42.86, $p < .001$		
Single-parent Family	*(n=752)*	*(n=1,711)*	*(n=2,644)*	*(n=668)*	*(n=1,919)*	*(n=2,197)*
Yes	6.8	15.0	12.8	9.0	15.3	14.7
No	93.2	85.0	87.2	91.0	84.7	85.3
	χ^2 (10) = 32.18, $p < .001$			χ^2 (10) = 17.23, $p < .001$		
Residential Location	*(n=754)*	*(n=1,718)*	*(n=2,653)*	*(n=672)*	*(n=1,921)*	*(n=2,205)*
Metropolitan	1.2	21.7	79.2	0.7	26.5	78.2
Rural	94.7	76.7	20.7	94.0	71.7	21.7
Remote	4.1	1.6	0.1	5.2	1.8	0.1
	χ^2 (4) = 2199.59, $p < .001$			χ^2 (4) = 1797.50, $p < .001$		

Table 5. General linear models for dmfs (4–9-year-olds)

	0% lifetime F access			1–99% lifetime F access			100% lifetime F access		
Models	F	Sig.	η^2	F	Sig.	η^2	F	Sig.	η^2
Model 1	n = 727, R^2 = .05			n = 1686, R^2 = .02			n = 2572, R^2 = .03		
Sex	6.36	.012	0.01	8.36	.004	0.01	3.58	.059	0.00
Age	26.62	.000	0.03	14.80	.000	0.01	21.54	.000	0.01
% Non-public	0.64	.589	0.00	1.29	.276	0.00	15.68	.001	0.02
Model 2	n = 629, R^2 = .13			n = 1474, R^2 = .05			n = 2234, R^2 = .06		
Sex	7.28	.007	0.01	8.03	.005	0.01	2.07	.151	0.00
Age	23.82	.000	0.04	10.13	.001	0.01	14.10	.000	0.01
Income	0.97	.426	0.01	1.08	.364	0.00	3.11	.015	0.01
Education	5.50	.001	0.03	0.72	.542	0.00	3.27	.020	0.00
Occupat. Prestige	2.20	.068	0.01	2.46	.043	0.01	1.43	.220	0.00
Family type	0.41	.521	0.00	0.47	.492	0.00	0.02	.876	0.00
Residential Locat.	1.54	.216	0.01	3.12	.044	0.00	9.19	.000	0.01
Brushing Freq.	2.70	.101	0.00	0.22	.641	0.00	9.04	.003	0.00
Fluor. Tablet Use	0.47	.625	0.00	5.42	.005	0.01	5.39	.005	0.01
% Non-public	1.03	.381	0.01	1.68	.169	0.00	3.81	.010	0.01

Table 6. General linear models for DMFS (10–15-year-olds)

	0% lifetime F access			1–99% lifetime F access			100% lifetime F access		
Models	*F*	Sig.	η^2	*F*	Sig.	η^2	*F*	Sig.	η^2
Model 1	n = 650, R^2 = .11			n = 1884, R^2 = .07			n = 2143, R^2 = .10		
Sex	2.88	.090	0.00	1.63	.202	0.00	0.64	.423	0.00
Age	70.50	.000	0.10	134.06	.000	0.07	222.31	.000	0.09
% Non-public	1.09	.354	0.01	1.60	.188	0.00	0.60	.612	0.00
Model 2	n = 523, R^2 = .16			n = 1593, R^2 = .09			n = 1795, R^2 = .12		
Sex	4.22	.040	0.01	3.37	.067	0.00	0.13	.715	0.00
Age	53.90	.000	0.10	108.70	.000	0.07	199.13	.000	0.10
Income	0.57	.685	0.01	1.89	.109	0.01	1.88	.112	0.00
Education	0.96	.410	0.01	2.78	.040	0.01	0.46	.709	0.00
Occupat. Prestige	2.43	.047	0.02	0.60	.666	0.00	0.89	.472	0.00
Family type	0.41	.523	0.00	0.09	.764	0.00	0.10	.747	0.00
Residential Locat.	0.19	.824	0.00	1.06	.347	0.00	2.24	.107	0.00
Brushing Freq.	4.27	.039	0.01	7.23	.007	0.01	5.26	.022	0.00
Fluor. Tablet Use	1.06	.348	0.00	0.39	.678	0.00	6.32	.002	0.01
% Non-public	2.29	.078	0.01	1.38	.247	0.00	0.71	.548	0.00