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Lifetime fluoridation exposure and dental caries experience in a military population

Gregory Mahoney[1], Gary D. Slade[2], Scott Kitchener[1] and Adrian Barnett[1]
[1]Centre for Military and Veteran's Health, School of Population Health, University of Qld, Qld, Australia, [2]Australian Research Centre for Population Oral Health, University of Adelaide, SA, Australia

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Abstract – While there is good evidence of caries-preventive benefits of fluoride in drinking water among children and adolescents, there is little information about effectiveness of water fluoridation among adults. *Objectives:* To determine whether exposure to fluoride in drinking water is associated with caries experience in Australian Defence Force (ADF) personnel. *Methods:* Cross-sectional study of 876 deployable ADF personnel aged 17–56 years. At each person's mandatory annual dental examination, military dentists recorded the number of decayed, missing and filled teeth (DMFT) using visual, tactile and radiographic criteria. Participants also completed a questionnaire, listing residential locations in each year from 1964 to 2003. People were classified into four categories according to the percentage of their lifetime living in places with fluoridated water: <10%, 10% to <50%, 50% to <90% and ≥90%. Mean DMFT was compared among those categories of fluoridation exposure and the association was evaluated statistically using analysis of variance to adjust for age, sex, years of service and rank. *Results:* Without adjustment for confounders, the mean DMFT (±95% confidence interval) was 6.3 ± 0.8 for <10% fluoridation exposure, 7.8 ± 0.8 for 10% to <50% exposure, 7.5 ± 0.7 for 50% to <90% exposure and 4.6 ± 0.6 for ≥90% exposure ($P < 0.01$). However, age was inversely associated with mean DMFT and in the <10% exposure group, 91% of people were aged <35 years. Service rank was also significantly associated with both fluoridation exposure and DMFT. After adjustment for all covariates, mean DMFT was 24% lower among people in the two groups with ≥50% exposure compared with the <10% exposure group. *Conclusions:* Degree of lifetime exposure to fluoridated drinking water was inversely associated with DMFT in a dose–response manner among this adult military population.

Key words: assessment; dental caries; epidemiology; fluoridation; military personnel

Gregory Mahoney, Gregory Herston Road, Herston, Brisbane, Qld 4006,Australia
Tel: +61 7 3346 4913
Fax: +61 7 3346 4878
e-mail: g.mahoney@uq.edu.au

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Backgound

Fluoridation of drinking water has been widely adopted within Australia with almost 70% of the population living in places where the water contains around 1ppm fluoride (1). While its effectiveness in reducing dental caries in children (2–7) has been established, the same cannot be said for the adult population. In a meta-analysis of studies evaluating its impact in adults, water fluoridation was found to confer a 27% reduction in rates of dental decay for adults exposed to water fluoridation (8). A 2003 study of Australian Army recruits found that the average number of decayed missing filled or surfaces (DMFS) per person varied according to lifetime exposure to fluoride in drinking water. The mean DMFS was 7.5 per person who had lived all of their lives in areas served by fluoridated drinking water compared with 10.5 DMFS per person ($P < 0.001$) for those with no exposure to fluoride in drinking water (9). Additionally the study found that gender, age and socioeconomic status had a statistically significant impact on the caries experience. Another study of

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Australian naval recruits found a significantly lower mean DMFT (teeth) per person for 15 to 29-year olds living in fluoridated communities compared with non fluoridated communities (10).

It is no coincidence that Australian Defence Force personnel have been the subject of a number of these studies as they represent a reasonably homogeneous population of otherwise young healthy adults. However, the above studies and others have acknowledged limitations due to difficulties in the determination of lifetime fluoride exposure and the limited age range of the population (11).

Water fluoridation commenced in Australia in 1953 in Beaconsfield, Tasmania. Population access to fluoridated water increased significantly between 1964 and 1977 when water supplies were fluoridated in seven of Australia's eight capital cities and in other population centres. One consequence of this history is that there is now marked variation in lifetime exposure to fluoride in drinking water among adults in the Australian population. The aim of this study was to determine if variation in lifetime exposure to fluoride in drinking water was associated with dental caries experience of Australian military personnel. We hypothesized that the association would be represented as a gradient, in which greater degree of lifetime exposure to fluoridated drinking water would be associated with progressively lower levels of dental caries experience.

Methodology

A cross-sectional study was conducted among 876 deployable personnel in the Australian Defence Force (ADF) stationed at seven ADF bases. The bases were selected purposefully because they had the largest numbers and highest proportion of deployable personnel from among the 79 bases that houses Australia's deployable personnel. They were located in four Australian jurisdictions: New South Wales, Victoria, Queensland and the Northern Territory. Study subjects were selected at the time of their mandatory annual dental examination (ADE), with the intention to enroll approximately 10% of personnel at each base. Inclusion criteria were that the ADF member had to be deployable, meaning that the member was posted to a position which may or may not involve an overseas deployment. It also meant that the member had to maintain a certain level of physical fitness and health including oral health. Those members who indicated that they were likely to separate from the ADF in the next 12 months were excluded. Enrolment was to be achieved by selecting all subjects who completed their ADE within a period of five consecutive weeks during 2006. Where enrolment was slower than expected, the period was extended in an attempt to enroll the target of 10% of the base's population. In fact, enrolment occurred over periods of up to 3 months. The study was explained to potential participants, and those who provided signed, informed consent were asked to complete a questionnaire and information about dental caries was recorded by military dentists during the ADE. This data collection was undertaken to provide baseline data for an ongoing, prospective cohort study that is investigating unplanned dental visits among military personnel.

The questionnaire was similar to the 2004–2006 National Survey of Adult Oral Health (NSAOH) so as to gain comparative data (12). The questionnaire asked participants where they had lived for each year during the period 1964–2003. Respondents recorded either the name of the locality or its postcode. The fluoride concentration and the year of fluoridation of the water supply of each postcode in Australia were determined by linking these responses to a database of fluoride concentrations for all Australian localities, maintained by the Australian Research Centre for Population Oral Health's. Lifetime Fluoridation Exposure (LFE) using the method described by Grembowski (13). In summary, the number of years living in places with fluoridated drinking water was divided by the study participant's age, and multiplied by 100 to yield the percentage of lifetime exposed to fluoridated water. For the purposes of this study, years lived outside Australia were ignored in computing residential history, and no distinction in fluoride concentrations were made between 0.5 and 1ppm. The questionnaire also asked about the use of fluoride supplements during childhood and receipt of professionally applied fluorides. Additional questions asked about age, sex, military rank and years of military service.

The number of teeth that were decayed (D), missing because of dental decay (M) or filled because of dental decay (F) was recorded by military dentists using visual, tactile and radiographic criteria. Military dentists follow standard operating procedures when diagnosing those conditions, using criteria based on those developed by the World Health Organisation (14). Additionally, each participating dental centre received a briefing on the conduct of the study. However, they were not otherwise calibrated. The findings of the oral examination were recorded in the participants' clinical records and transcribed onto an electronically readable paper form which was bar coded to match the questionnaires. For the purposes of validation, 14% of the returns were audited by the senior dental officer at the participating bases. Defined significant variations in the audited returns triggered a review of all returns of the examination dentist. In addition to the DMFT and fluoride exposure data, demographic characteristics such as age, gender, years of service and rank were also recorded. Service rank was split into four categories: (i) Officer – any commissioned officer in the ADF; (ii) SNCO – senior noncommissioned officer which included the ranks of sergeant and warrant officer equivalents; (iii)JNCO – junior non commissioned officer which included the ranks of corporals a lance corporal equivalents and (iv) Other ranks any ranks below JNCO.

In the analysis, the DMFT was the dependent variable which was compared among four categories of lifetime fluoridation exposure: <10%, 10% to <50%, 50% to <90% and ≥90%. The difference in DMFT by lifetime fluoridation exposure was evaluated using analysis of variance. Age, sex, years of service and rank were assessed as potential confounders, first by evaluating associations between each confounder and DMFT, and then between each confounder and lifetime fluoride exposure. Because age was such an important potential confounder, both on theoretical and empirical grounds, it was used as a stratifying variable to investigate potential age-related variation in the association between fluoridation exposure and DMFT. Potential confounders that were significantly associated with both DMFT and lifetime exposure (as judged by $P < 0.05$), or that had been shown in previous studies to be important predictors of caries experience (4, 15) were used as additional explanatory variables in a generalized linear model in which DMFT was the dependent variable, and fluoride exposure was the main explanatory variable. Potential effect modification between significant covariates was evaluated in the same model by testing for a multiplicative interaction.

Sample size for the study was based on requirements for the prospective cohort study that were unrelated to this analysis. Instead, we made a *post hoc* calculation of statistical power for the recruited sample of 847 subjects using STATA software to make a two-sample comparison of means for the observed distribution of DMFT between high-and low-exposure groups. Using the observed distribution of DMFT, where standard deviation was 5.2, we found 92% power to detect a 20% difference in mean DMFT with a two-tailed test with type I error of 5%.

Results

A total of 1025 questionnaires were distributed to the seven ADF bases/ships in Australia and 876 useable questionnaires were returned representing an 85% response rate. The response rate might have been higher except for the operational tempo and available manpower of some of the establishments. Study subjects were aged 17–56 years (mean = 29.8 standard deviation = 7.8 years) and 11% were female. Their demographic distribution and rank structure (officer 15% senior noncommissioned officer 18%, junior non commissioned officer 24% and other ranks 43%) were representative of the deployable population. However the entire ADF population differed from the study population in that the ADF population had longer years of service, on average, which was not unexpected given the younger age of a deployable population.

Just over one half of study participants had lived 50% or more of their lifetime in fluoridated areas, and the association of lifetime fluoride exposure and mean DMFT was found to be statistically significant (Table 1). However, the relationship was not monotonic, with mean DMFT being greatest (7.8) among people with 10% to <50% of lifetime exposed to fluoridated water and lower for people with <10% lifetime exposure.

Assessment of confounding

There was an expected linear increase in mean DMFT scores as the age group increased (4.0–14.0), at the significant level ($P < 0.001$), suggesting that

Table 1. The Mean Decayed, missing, and filled teeth (DMFT) (and 95% confidence interval) by lifetime fluoridation exposure

Lifetime fluoridation exposure	% of people	Mean DMFT	95% Confidence interval
<10%	20.7	6.3	5.5, 7.1
10% to <50%	24.9	7.8	7.0, 8.6
50% to <90%	25.4	7.5	6.7, 8.2
≥90%	29.0	4.6	4.0, 5.1

Table 2. Association between potential confounders and mean Decayed, missing and filled teeth (DMFT) and lifetime fluoridation exposure (LFE) (%)

				% with LFE			
Covariate	*n*	Mean DMFT	95% CI	<10%	10 to <50%	50 to <90%	>90%
Age							
17–24	298	4.0	3.6, 4.5	31.2	17.5	11.2	40.1
25–34	333	6.1	5.6, 6.6	20.3	26.1	23.7	29.8
35–44	209	9.5	8.8,10.2	7.3	35.2	45.4	12.1
45+	36	14.0	12.2,15.8	3.3	23.3	60.0	13.3
Gender		F (3, 865) = 92.6 P < 0.001			Pearson $\chi^2(9)$ = 138.7 P < 0.001		
Male	778	6.5	6.1, 6.9	21.1	25.7	25.3	27.8
Female	98	6.6	5.5, 7.7	17.2	18.4	26.4	37.9
Rank		F (1, 867) = 0.02 P = 0.88			Pearson $\chi^2(3)$ = 5.0 P = 0.17		
Officer	133	6.0	5.2, 6.9	17.8	29.4	30.4	28.4
SNCO	162	9.4	8.5, 10.3	7.3	35.0	44.5	13.1
JNCO	206	6.5	5.8, 7.2	24.5	29.3	22.3	23.9
Other	375	5.4	5.0, 5.9	26.8	16.8	17.8	38.6
Years of service		F (3, 865) = 23.6 P < 0.001			Pearson $\chi^2(9)$ = 92.6 P < 0.001		
0–5	431	5.2	4.7 5.6	29.0	20.5	13.3	37.2
6–10	145	6.1	5.3, 6.9	16.1	29.7	23.7	30.5
11–15	99	6.5	5.5, 7.5	10.3	28.7	37.9	23.0
16–20	110	9.0	8.0, 10.0	6.9	23.2	39.4	11.5
20+	64	11.7	10.6,12.8	3.9	25.5	60.8	9.8
		F(4, 842) = 26.4 P < 0.001			Pearson $\chi^2(12)$ = 138.5 P < 0.001		

age may be a confounder (Table 2). As expected, the degree of lifetime fluoridation exposure was also associated with age. Neither DMFT nor fluoridation exposure were significantly associated with gender. While there appeared to be little difference between the genders, the findings of other studies warrant gender's inclusion in any regression analysis, hence it was retained (4, 9, 15). Rank was significantly associated with mean DMFT (P < 0.001) and with exposure to fluoridation (Table 2) and for that reason, rank was retained for subsequent multiple regression analysis.

Participants' years of service and age were necessarily related, so it was not surprising that there was a linear relationship between participants' year of service and mean DMFT (P < 0.001). As years of service was also associated with fluoridation exposure, it was also retained for multiple regression analysis.

The general pattern of decreasing mean DMFT for groups with successively greater exposure to fluoridation was observed within most age strata (Table 3). Specifically, when comparing lowest and highest exposure groups, there was a 20% difference in mean DMFT score among 17 to 24-year olds, a 38% difference among 25 to 34-year olds, and a 35% difference among 35 to 44-year olds.

When DMFT was used as the dependent variable in the generalized linear model fluoride exposure, age and rank were statistically significant (P < 0.005) while gender and years of service were not statistically significant (Table 4). Although not shown in the table, an additional model found nonsignificant interactions between rank and LFE (P = 0.56) and between age and LFE (P = 0.46) demonstrating that the effects of fluoride exposure on DMFT across rank and age groups were similar.

Adjusted means from the generalized linear model were computed to illustrate the relationship between LFE and DMFT after adjustment for confounders (Fig. 1). Figure 1illustrates two important results. First, when adjusted for age, the mean DMFT of those who had lived >90% of their life in areas with fluoridated water was 1.8 teeth (24%) less than those who received <10% exposure. Secondly, the decrease in mean DMFT revealed a plateau in the protective effect higher levels of lifetime exposure (>90%).

Discussion

The main finding from this study was that the dental caries experience was significantly related to the degree of exposure to fluoridated drinking water, and that the relationship followed a dose–response pattern after adjustment for confounding variables, primarily age. This result is consistent with observations from Australian studies of child populations (15–17), and extends findings reported

Table 3. Age-stratified analysis of decayed, missing and filled teeth (DMFT) and lifetime fluoridation exposure (LFE)

	Mean [a]DMFT (95% confidence interval) lifetime fluoridation exposure				
Age group	<10%	10% to <50%	50% to <90%	≥90%	Prevented fraction [d]
Mean					
17–24	4.5	4.5	4.1	3.4	24.4%
CI	3.7–5.4	3.3–5.7	2.9–5.4	2.7–4.1	
n[b]	84	47	30	108	
Mean					
25–34	7.8	6.7	5.4	4.8	38.5%
CI	6.5–9.1	5.7–7.8	4.3–6.6	4.0–5.5	
n	60	77	58	88	
Mean					
35–44	11.3	11.2	9.1	7.3	35.7%
CI	8.0–14.7	9.8–12.6	8.1–10.2	5.1–9.4	
n	12	58	75	20	
Mean					
45–56	[c]	14.3	13.9	14.8	n/a
CI		7.0–21.6	11.2–16.7	9.8–19.7	
n	1	7	18	4	

[a] DMFT, decayed, missing and filled teeth.
[b]Data from 759 participants for whom lifetime fluoride exposure could be determined.
[c] Insufficient numbers to make a determination.
[d] Prevented fraction = (DMFT of <10% LFE – DMFT of >90% LFE) ÷ DMFT of <10% LFE × 100.

Table 4. Generalized linear model of number of decayed, missing and filled teeth (DMFT)

	Change in mean DMFT	*p*-value	95% Confidence interval
Rank (ref. officer)			
SNCO	1.6	0.01	0.4, 2.7
JNCO	1.6	0.00	0.5, 2.7
Other rank	1.7	0.00	0.7, 2.8
Age (centered at the mean age of 29)	0.4	0.00	0.3, 0.5
Years of service (increments of 5 years)	−0.2	0.43	−0.6, 0.2
Lifetime fluoride exposure (ref <10%)			
10% to <50%	−0.4	0.41	−1.4, 0.6
>50% to 90%	−1.4	0.01	−2.4, −0.4
≥90%	−1.8	0.00	−2.6, 0.9
Gender (ref. female)	−0.7	0.18	−0.3, 1.6
Intercept	5.3	0.00	3.6, 7.0

Adj R^2 = 0.2967.
SNCO, senior noncommissioned officer; JNCO, junior noncommissioned officer.

by Hopcraft and Morgan (9) who studied a younger cohort of newly recruited military personnel. Before considering the public health significance of this study's results, the discussion that follows considers aspects of the population studied, and the methods used to measure fluoridation exposure and caries experience.

The Population

The deployable ADF population in this study is not representative of the Australian population in that they represent a healthy and fit group with a male bias drawn from a relatively homogenous socio-economic background and they receive free dental care. However, it is because they are a healthy and fit group who receives free dental care that they represent a valuable population for this study, as the potential confounding created by variation in access to dental care by and large have been eliminated.

Fluoride Exposure

Collecting participants' fluoride exposure for each year of the participants' lives is an important feature of this study. The exposure during time spent overseas could not be determined, and it was

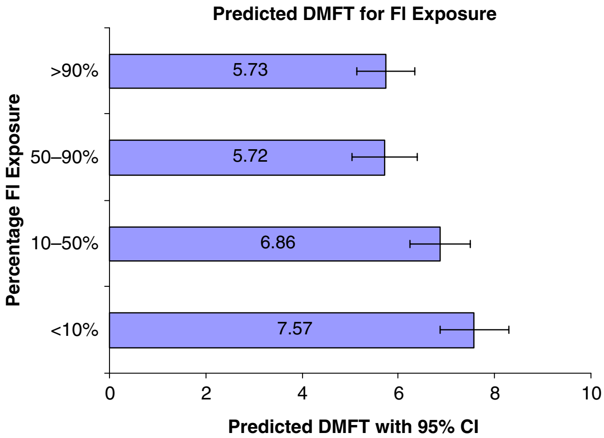

Fig. 1. Adjusted Mean* Decayed, missing and filled teeth (DMFT) by Lifetime fluoridation exposure (LFE). *Adjusted means are from generalized linear model shows in Table 4.

known that some of these people were in areas where water fluoridation existed. It follows that the results while accurately reflecting their Australian fluoride exposure may be under representing participants' total fluoride exposure for those participants who had resided overseas for a significant period.

Participants were asked about their fluoride supplement experience and, while 88 responded positively to taking fluoride tablets or drops when young, very few of them could recall when they started fluoride supplements, when they stopped, how often they took it, or in what amount. Because of these understandable limitations in recollection, this study had limited capacity to assess any effect of supplements on caries in adulthood. However, it remains possible that a preventive benefit exists in this military population (18).

When designing the questionnaire, we felt it would be unreasonable to expect participants to accurately recall their pattern of water consumption during the periods when they lived at each locality. For that reason, the main explanatory variable in this study was the percentage of lifetime exposed to fluoridated drinking water, and not the amount or frequency of consumption of such water. In fact, participants living in fluoridated areas may have consumed nonfluoridated water, either from domestic rainwater tanks or from imported bottled water. Conversely, people living in non-fluoridated areas probably consumed some manufactured foods that were prepared using fluoridated water. This latter phenomenon is referred to as the 'halo effect', and one consequence is that studies such as this that measure exposure, not consumption, probably underestimate the strength of the relationship between caries and fluoride in drinking water (19).

Measurement of dental caries experience

For this study the DMFT index was used as a measure of lifetime caries experience while other studies have used the more sensitive measure of DMFS (9, 10). This decision was taken because it was believed that DMFT was a more robust measure less susceptible to examiner bias and miscalculation as the study was conducted in a number of centres with 23 dentists recording the score. Yet, because DMFT is a less sensitive measure of caries experience, it is likely that this study has underestimated the true benefit of fluoridation.

Public health significance

The dose-related response of increasing fluoride exposure and lower mean DMFT observed in this study is consistent with other findings in children, adolescence and ADF recruits (9, 10, 17, 20, 21). The percentage difference of 24% in between adjusted mean DMFT for people with ≥50% lifetime exposure compared with people with <10% lifetime exposure (Fig. 1) is similar to the prevented fraction of 27% reported by Griffin et al. (22), and is consistent with the findings of Burt et al. (17) and Clark et al. (21). This result confirms that continued fluoride exposure through adulthood leads to lower dental caries experience. Percentage differences varied from 24% among 17 to 24-year olds to 38% among 25 to 34-year olds (Table 3), but there were very few people aged 45 years or more to reliably estimate the percentage difference within that age group.

Influence of factors other than fluoridation exposure

The absence of a significant difference in DMFT between males and females ($P = 0.177$) was surprising. Hopcraft found that gender had a significant association with caries experience in a military recruit population and others found to be significant in children (4, 9, 15, 23). Certainly there are measurable differences in mean DMFT between males and females over a range of years. The number of years of service participants had was not significant ($P = 0.426$) when adjusted for the other variables.

Service rank was viewed as potential confounder and while rank in the nonofficer cohort is related to years of service and age, it is different from age in that higher rank also infers higher pay, better educational standard and increased workplace responsibilities. The effect of service rank confirms that officers have lower mean DMFT than the other ranks after taking into account the effects of age and fluoridation exposure. The finding is consistent with other research that has reported socioeconomic gradients in oral health among children (4) and adults (24). Given that this population receives free, comprehensive and compulsory dental care across the rank structure, then other factors are contributing to this measured difference. In the ADF, higher ranks receive higher pay and they generally have higher levels of education (25) than lower ranks. Association between rank and DMFT in this study may, in part, be due to their attitude and behaviour to dental care within the rank structure or SES of their upbringing as well their DMFT on entry to the ADF however this is certainly beyond the scope of this study.

Conclusion

In this study of ADF personnel, a greater degree of lifetime exposure to water fluoridation was associated, in a dose–response manner, with lower DMFT scores in adults between the ages of 17–44. Adults who had spent at least 90% of their lifetime living in places with fluoridated water had 24% lower mean DMFT per person than people of a similar age who had been exposed to fluoridated water for <10% of their lifetime. The findings provide evidence that exposure to fluoride in drinking water confers benefits on dental health of adults.

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