Association of natural fluoride in community water supplies with dental health of children in remote Indigenous communities – implications for policy

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Abstract

Objective: To map the geographic distribution of fluoride in water supplies and child dental caries in remote Indigenous communities of the Northern Territory (NT). To examine the association between fluoride levels, household and community factors, access to services and child dental caries in these communities and to model the impact on the caries experience of children of introducing water fluoridation.

Methods: Fluoride testing was conducted in 80 locations across the NT in 2001. Measures of mean caries experience for six-year-olds and 12-year-olds and community and housing-related infrastructure were obtained from records of the NT School Dental Service. Associations between community fluoride levels, community level variables and childhood caries experience and potential impact of water fluoridation were assessed using linear regression modeling.

Results: Mean caries experience for six- and 12-year-olds tended to be higher in northern and eastern areas of the NT, corresponding to the distribution of low levels of natural fluoride. Several-fold more children in remote NT communities are exposed to the risks of inadequate fluoride than are exposed to excessive fluoride. Mean reticulated fluoride level was the only variable significantly associated ($p<0.05$) with caries experience in both age groups. The potential reduction of caries through introducing water fluoridation is expected to be about 28% for children living in communities with the lowest levels of fluoride (<0.3 mg/L).

Conclusions and Implications: Introduction of fluoridation of water supplies into communities with inadequate natural fluoride is a vital measure for improving the dental health of children living in remote NT communities.

Key words: fluoride, dental caries, Indigenous, prevention, remote.

Aust N Z Public Health. 2009; 33:205-11
doi: 10.1111/j.1753-6405.2009.00376.x

The efficacy of fluoride in the prevention of dental caries is irrefutable.[1-4] The US Centers for Disease Control and Prevention named water fluoridation as one of the 10 greatest public health achievements in the 20th century[5] and fluoridation of water supplies has been established as the most cost-effective and socially equitable way of preventing dental decay in children and adults, providing 20-40% reductions in dental caries.[6,7]

Prior to the 1980s, Indigenous Australian children were recognised as having better oral health than non-Indigenous children.[8-11] However, recent evidence suggests that Indigenous children now have, on average, twice as much (and in some communities, up to five times as much) tooth decay as their non-Indigenous counterparts.[12-14] Young children in the Northern Territory (NT) generally have been identified as having among the poorest oral health of all States and Territories in Australia.[8]

The National Health and Medical Research Council (NHMRC) recently reaffirmed its recommendations for fluoridation of drinking water supplies[15] and Australia's National Oral Health Plan recommends the fluoridation of water supplies for all Indigenous communities of more than 1,000 people.[16] However, in the NT only the major centres of Darwin and Katherine have established systems for artificial fluoridation of water supplies. Outside the few major centres, 70% of the population in the NT are Indigenous and generally live in small dispersed communities. Feasibility trials in two such remote communities have demonstrated the potential for successful fluoridation of remote community water supplies,[17] and the NT Government is considering plans for water fluoridation in other communities.

Levels of natural fluoride are known to vary widely across the NT, and should be an important consideration in water fluoridation

Submitted: June 2008 **Revision requested:** November 2008 **Accepted:** February 2009

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initiatives. The national Community Housing and Infrastructure Survey (CHINS) shows that remote community water supplies in the NT are almost exclusively derived from ground water via bores and that use of rainwater tanks for drinking supplies is rare.[18] There are generally no other readily accessible sources of water for drinking or cooking in these communities aside from bottled water purchased in community stores. The community water supplies are therefore an essential source of water for drinking and cooking. Even where people do not drink water as such, community water supplies remain a major potential source of natural fluoride through use in cooking and drinks such as tea. Ingestion of excessive fluoride during tooth formation can lead to dental fluorosis with a change in the appearance of teeth. This is generally not considered to be a toxic effect[19] and in some cases is associated with greater cavity resistance.[20] Despite the relatively innocuous consequences of high levels of natural fluoride in water supplies, concerns regarding excessive fluoride in some communities have led to the spending of $100,000 on a unit to reduce the level of fluoride in the water supply of one community.[21] Australian Drinking Water Guidelines (ADWG)[22] provide no advice on the relative impact on public health of inadequate compared to excessive levels of fluoride in water supplies.

Community level factors have long been recognised to have an impact on health. The social ecological theory posits health behaviours are influenced by individual and area environmental characteristics (e.g. interpersonal, family, schools, and community).[23] The contribution of household and community level determinants in caries experience has not been previously described in NT Indigenous populations. This study describes the statistical association between levels of naturally occurring fluoride, household and community factors, access to services and child dental caries experience for communities across the NT. In addition, the study provides an analysis of the expected impact on child caries if recommended levels of fluoride in community water supplies were achieved. For the purpose of informing the policy direction of fluoridation technology in the NT, this study also maps the geographic distribution of fluoride in water supplies and of child dental caries in remote communities in the NT.

Methods

Testing for fluoride was conducted in 80 locations across the NT in 2001 as part of an NT Government water quality monitoring program. Sampling was conducted in the driest part of the year before major rains set in. Although no information was available on seasonal fluctuations of natural fluoride, the time of year for collection of water samples was influenced by the expectation that an increased volume and flow of water during the wet season might lead to decreases in fluoride concentrations. Our analysis used fluoride levels from water samples from the community reticulation system. Where there were samples from more than one point in the reticulation system the mean level was used.

The fluoride analysis followed the internationally accepted Ion-Selective Electrode Method,[24] whereby a fluoride electrode is used to measure the ion activity of fluoride in solution, using a buffer to provide a uniform ionic strength background, adjust pH and break up complexes such as aluminium and iron, and hydrogen complexes.

There are two different measures of caries, one used for younger children with deciduous teeth (the sum of Decayed, Missing because of caries, or Filled deciduous Teeth, or dmft [lower case]) and another for older children with permanent teeth (the sum of Decayed, Missing because of caries, or Filled permanent Teeth, or DMFT [upper case]). Measures of the mean dmft for six-year-olds and DMFT for 12-year-olds were obtained from the Child Dental Health Survey (CDHS) database for the Northern Territory for the five combined years 1998 to 2002 (held by the Australian Institute for Health and Welfare [AIHW] Dental Statistics and Research Unit). The CDHS is a national surveillance survey involving the collection of caries experience data as part of the service provision of the School Dental Services. The dataset included the data reported for all children examined for all locations outside Darwin.

Schools where data were available for less than six children for the age groups of interest were excluded from analyses because small numbers limited the potential generalisability of estimates. An additional two schools were excluded from the analysis when a matched community level fluoride reading could not be identified. Where fluoride data were not available for a community of interest, fluoride levels from communities within 20 km were substituted as estimates. Data from one school was excluded because the recorded count for children was unusually high given the population of the community, raising doubts about whether the data from this school could be regarded as representative of that community. Geographic coding in this dataset was by the community in which schools are based.

Household and community level factors, that might represent potential confounders for child caries experience, were provided by the 2001 Community Housing and Infrastructure Needs Surveys (CHINS). The CHINS was conducted by the Australian Bureau of Statistics on behalf of the Aboriginal and Torres Strait Islander Commission (ATSIC) with the aim of assessing the status of community and housing related infrastructure in discrete Indigenous communities.[18] The variables selected for inclusion in the analysis were 1) distance from a major service centre; 2) the community size (in terms of population numbers); 3) the quality of housing infrastructure; 4) the availability of community facilities for social and cultural purposes, such as halls, libraries, youth or women's centre's and pubs or clubs; 5) access to health and dental

Table 1: Number of communities (%) and reported population (%) by level of fluoride in the reticulated water supply (analysis limited to communities with fluoride data available).

Fluoride levels (mg/L)	Number of Aboriginal communities (%)	Reported population (%)
<0.30	26 (40.6)	22,351 (65.4)
0.30-0.59	17 (26.6)	5,343 (15.6)
0.60-1.10	12 (18.8)	2,886 (8.4)
>1.10	9 (14.1)	3,597 (10.5)
Total	64 (100)	34,177 (100)

services in the community and 6) persons per dwelling, used as a proxy measure for overcrowding (Table 1 and 2).

A child caries experience map was produced by geo-coding the data points of schools/communities and using graphic symbols to represent caries experience scores. For the map of fluoride levels, community locations were geo-coded and a grid surface map was created. An inverse distance weighting (IDW) interpolator function was applied to calculate distance weighted average of data points to grid cell values. The influence of each data point on another was determined by a radius setting of 300 km. The software used was MapInfo Professional.

For the purpose of analysis of associations between the mean caries experience of children in the community, community fluoride levels and other community variables, the community fluoride levels were categorised according to the NHMRC recommendations for fluoridation of water supplies:[7] <0.3, 0.3-0.59, 0.6-1.1, >1.1, with the lowest category being <50% of the lower limit of the recommended range. Associations between community fluoride levels and the selected CHINS variables, and caries experience (in six- and 12-year-olds) were calculated using simple linear regression. Preliminary analysis revealed a number of curvilinear associations, including mean reticulated fluoride concentration with dental caries. Therefore, continuous variables were converted to quartiles. Explanatory variables showing a moderate (i.e. $p<0.20$) association with caries experience were then analysed in a multiple linear regression model and backward selection of variables carried out ($p>0.10$ for removal). Cross-products were calculated to test for interactions and final models

Table 2: Community characteristics (%).

	six-year-olds (n=50 communities)	12-year-olds (n=47 communities)
Community reported population		
Less than 200	14.0	8.5
200-399	38.0	31.9
400-699	24.0	29.8
700 or more	24.0	29.8
% of houses requiring major repairs or replacement	24.8	26.6
% population in temporary housing		
Less than 5%	78.0	80.9
5% or more	22.0	19.1
Community facilities		
Hall/meeting area in community	70.0	74.5
Library in community	34.0	36.2
Women's centre in community	84.0	85.1
Youth centre in community	32.0	38.3
Club/pub in community	38.0	36.2
Secondary school 50 km distant	76.0	70.2
Proximity of health centre to Community		
In community	94.0	93.6
10 km or more	6.0	6.4
Community visits by dentist		
No visits	16.0	10.6
Less than three monthly	36.0	34.0
Three monthly	20.0	21.3
Monthly	16.0	19.2
Daily, weekly or fortnightly	12.0	14.9

Table 3: Unadjusted and adjusted means (95% confidence intervals) from multivariate models of mean dental caries for six- and 12-year-olds.

Explanatory variables	Six-year-olds (n=50 communities): Adj. R^2=21.3% Unadjusted Mean dmft (95% CI)	Adjusted[a] Mean dmft (95% CI)	% change	12-year-olds (n=47 communities): Adj. R^2=22.1% Unadjusted Mean DMFT (95% CI)	Adjusted[a] Mean DMFT (95% CI)	% change
Overall mean	3.4 (2.9-3.8)	2.7 (1.6-3.9)	-20.6	1.1 (0.9-1.3)	1.1 (0.7-1.6)	0.0
Mean fluoride levels (mg/L)						
<0.3	4.3 (3.6-5.0)	3.1 (1.8-4.3)	-27.9	1.4 (1.1-1.7)	1.2 (0.7-1.7)	-14.3
0.3-0.59	2.7 (2.3-3.2)	2.5 (1.4-3.6)	-7.4	0.9 (0.6-1.1)	1.0 (0.6-1.5)	11.1
0.6-1.1	2.5 (1.3-3.7)	2.5 (1.4-3.5)	0.0	0.9 (0.5-1.4)	0.9 (0.5-1.4)	0.0
>1.1	3.1 (1.7-4.5)	2.7 (1.5-3.9)	-12.9	0.6 (0.4-0.8)	1.2 (0.7-1.7)	100.0
Persons per dwelling (quartiles)						
3.50-6.00	3.2 (2.4-3.9)	2.7 (1.3-4.0)	-15.6	1.1 (0.7-1.5)	ns	-
6.23-7.26	2.4 (1.9-2.8)	2.0 (0.8-3.2)	-16.7	1.0 (0.6-1.4)	ns	-
7.27-9.99	3.6 (2.4-4.8)	3.0 (1.6-4.3)	-16.7	1.2 (0.8-1.6)	ns	-
10.00-17.31	4.2 (3.6-4.8)	3.3 (1.9-4.6)	-21.4	1.3 (0.9-1.6)	ns	-
Population in temporary dwellings						
<5% in temporary	3.6 (3.1-4.1)	2.9 (1.7-4.1)	-19.4	1.2 (1.0-1.4)	ns	-
5%+ in temporary	2.5 (1.9-3.1)	2.3 (1.1-3.6)	-8.0	0.9 (0.5-1.3)	ns	-
Community visits by dentist:						
No visits	3.7 (2.6-4.7)	ns	-	1.0 (0.4-1.6)	0.9 (0.3-1.6)	-10.0
Less than three monthly	2.7 (2.1-3.3)	ns	-	0.8 (0.6-1.0)	0.9 (0.5-1.4)	12.5
Three monthly	3.3 (2.4-4.2)	ns	-	1.2 (0.8-1.6)	1.3 (0.6-1.9)	8.3
Monthly	4.1 (3.4-4.8)	ns	-	1.2 (0.8-1.6)	1.1 (0.5-1.7)	-8.3
Daily/weekly/fortnightly	3.9 (1.7-6.1)	ns	-	1.7 (1.0-2.4)	1.6 (0.9-2.3)	-5.9

Notes:
a) Adjusted for level of fluoride 0.6 – 1.1 mg/L
ns Variable not significant (i.e. dropped in multivariate backward selection procedure, p>0.10)

were used to generate unadjusted and adjusted means. Unadjusted and multivariate adjusted means are presented to examine the potential effect of changing fluoride levels in drinking water. Stata v9.2 was used for all statistical analyses.

Research ethics approval for this project was obtained from the Top End Health Research Ethics Committee and the Indigenous sub-committee.

Results

Caries experience data for children in 67 of the 80 communities were obtained from the CHDS data for communities where fluoride data were also available. Relevant CHINS data were available for 64 of these 67 communities. In 14 of these communities there were dmft data for only five children or less, and in 17 of these communities there were DMFT data for only five children or less. Analyses of the association between dmft and fluoride level was therefore limited to 50 communities and between DMFT and fluoride levels to 47 communities.

Child caries experience and natural fluoride

The mean six-year-old dmft for communities included in this analysis was 3.4 (range 0.7-8.3) and the mean 12-year-old DMFT was 1.1 (range 0.2-2.9). There was a concentration of communities with the poorest dmft in the north-east (Figure 1). Patterns of natural fluoride in community water supplies follow a similar distribution with the north-east having particularly low levels of natural fluoride (Figure 2).

The great majority of people in discrete Indigenous communities in the NT live in areas where the levels of fluoride in local reticulated water supplies are inadequate for protection against dental caries (Table 1). From an assessment based on communities for which fluoride data are available, almost eight times as many people live in communities with levels of fluoride less than the lower limit of national guidelines for community water supplies of 0.6 mg/L than in communities where levels of natural fluoride exceed the upper limit of national guidelines of 1.1 mg/L.

Figure 1: Geographic distribution of communities by mean dmft.

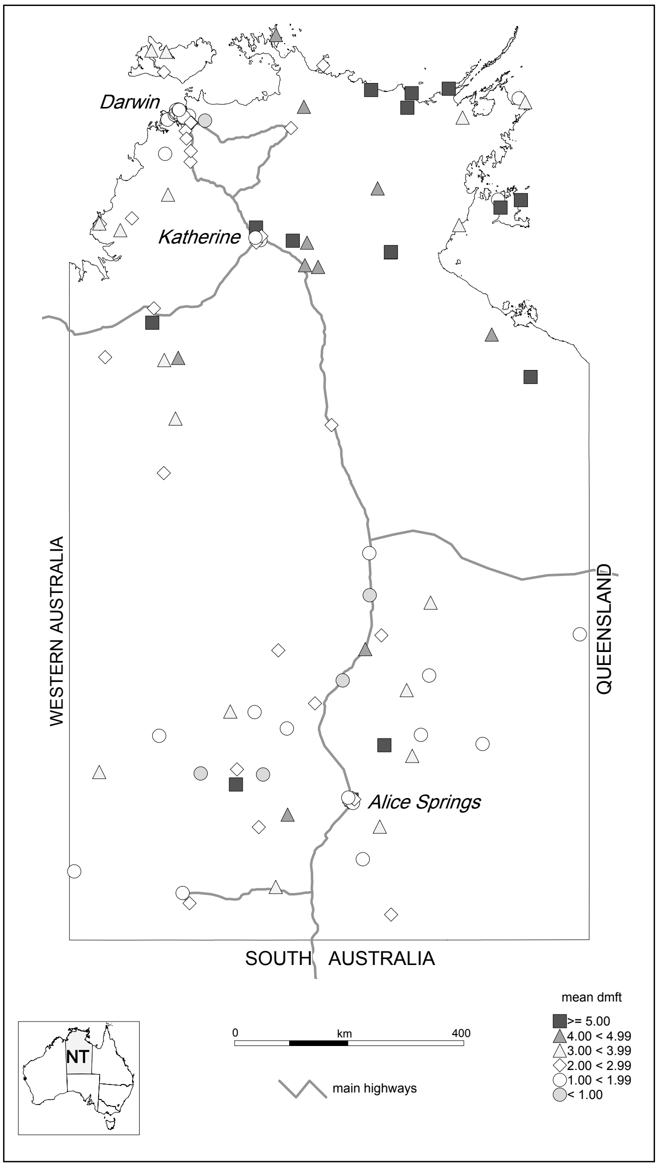
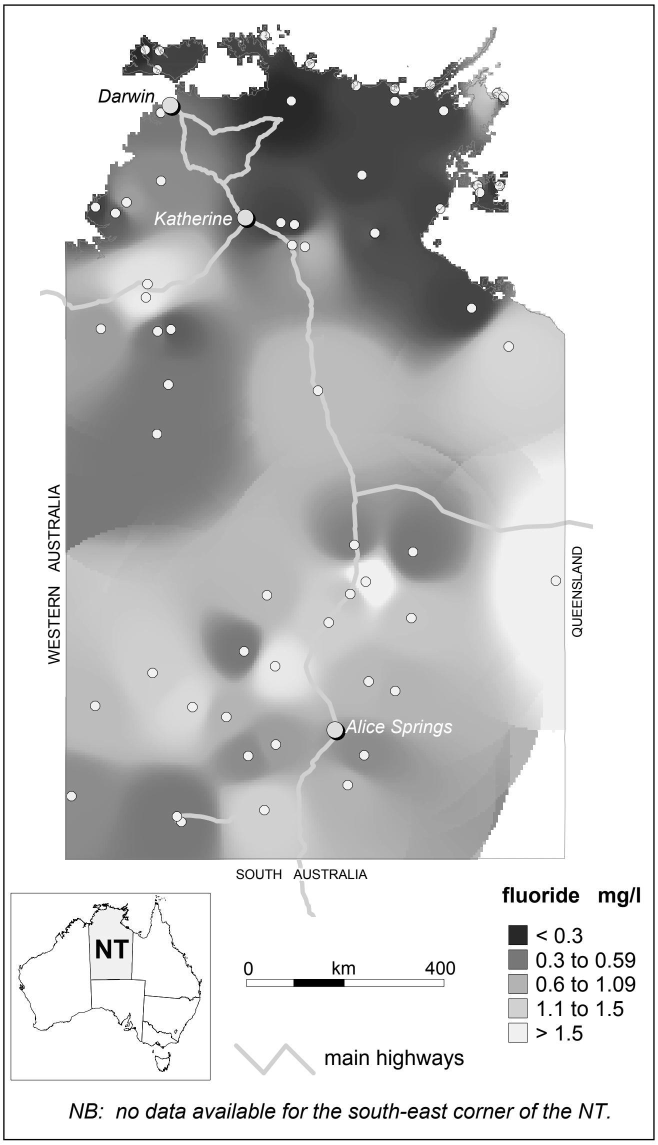


Figure 2: Geographic distribution of natural fluoride.



Child caries experience and household and community level factors

Analysis of the CHINS data show the communities for which caries data were available range in reported populations from 80 to 2,200 people. These communities were characterised by overcrowded dwellings (with a mean of seven persons per dwelling and an inter-quartile range of five to nine persons per dwelling). Many houses (about one in four) required major repairs or replacement (Table 1). Most communities have a primary health care centre, a women's centre and a hall or meeting area within the community. Relatively few communities have a youth centre or library, and less than one in four have a secondary school within 50 km. There were minimal differences in community characteristics between the 47 communities included in the 12-year-old DMFT analyses and the 50 included in the six-year-old dmft analysis, though the analyses for the 12-year-olds contained fewer smaller communities (39 communities were in both analyses).

Child caries, natural levels of fluoride and household and community level factors

In the bivariate analysis of community level factors associated with caries experience, mean reticulated fluoride level was the only variable to have a statistically significant association ($p<0.05$) with both six-year-old dmft and 12-year-old DMFT. Having a higher number of people per dwelling and a lower proportion of the population (<5% vs 5%+) in temporary dwellings were significantly ($p=0.05$) associated with a higher six-year-old dmft. Having a visiting dental service at more frequent intervals was associated with higher 12-year-old DMFT. The variables reflecting distance from a major service centre, community size, the percentage of houses requiring major repairs or replacement, the availability of community facilities, distance to schools, and access to a primary health care centre showed no significant association with mean caries experience.

The multiple regression models for dmft (six-year-olds) showed only marginally better explanatory power than the simple linear regression (R^2 of 21.3% compared to 20.2%) while for DMFT (12-year-olds) the explanatory power of the multivariate model was greater (R^2 of 22.1% compared to 17.0%) (Table 3). The unadjusted models show that communities with lower levels of fluoride and with more persons per dwelling tended to have higher mean dmft, while communities with 5% or more of people living in temporary dwellings tended to have lower mean dmft. For 12-year-olds, lower levels of fluoride and more frequent visits by a dentist were associated with higher mean DMFT.

The adjusted model estimates for mean six-year-old dmft if water fluoride levels were between 0.6 and 1.1 mg/L (reflecting the NHMRC guidelines) show the largest potential reduction in DMFT is expected to be for communities with levels of fluoride below 0.3 mg/L, with an estimated reduction of 4.3 to 3.1 dmft (28%). Estimated potential reductions of dmft for communities with other levels of fluoride were lower, ranging between 7% and 14% for communities with fluoride levels of 0.3 to 0.59 mg/L and greater than 1.1 mg/L respectively. Estimated potential reductions in mean dmft for communities with different levels of crowding were between 16% and 21%, with communities of higher levels of crowding appearing to have larger potential reductions in mean dmft. The average potential reduction in dmft if all communities had fluoride levels between 0.60 and 1.10 mg/L is estimated to be 21% (3.4 to 2.7 dmft).

Child caries experience at recommended levels of water fluoridation

The expected impact on child caries if recommended levels of fluoride in community water supplies were estimated using fluoride levels between 0.60 and 1.10mg/L. At this level of fluoridation, the model estimates for mean community 12-year-old DMFT showed no change in the overall mean DMFT. The largest potential reduction in DMFT (14%) would occur for communities with low natural levels of fluoride. At this level of fluoridation, the expected impact on caries for communities with regular visits by a dentist show a reduction of DMFT of 6-8%, and, increases in DMFT of 8 and 13% for communities that are visited by a dentist less regularly (every three months or less than three months).

Discussion

This research confirms the importance of fluoridation of water supplies as a vitally important strategy for prevention of dental caries in remote Indigenous communities in the NT. The implementation of this single intervention could be expected to result in a reduction in caries experience for six-year-olds of almost one-third in communities where water supplies have natural fluoride levels of <0.3 mg/L. The geographic distribution of levels of low natural fluoride is similar to that of communities with the highest childhood caries experience, and highlights the regions of the NT which will benefit the most from fluoridation of water supplies.

The less significant influence of fluoride levels in community water supplies for 12-year-olds compared to six-year-olds is expected and is consistent with results from recent studies of water fluoridation effectiveness.[25,26] Association of more caries experience among 12-year-olds with a greater frequency of visits by a dentist suggests that dental services are targeting communities with higher rates of caries. This is an appropriate strategy for a treatment rather than a preventive service, but needs to be recognised as a potential source of bias in interpretation of associations.

The findings of this study are potentially limited by several factors. First, the grid maps are based on a relatively small number of data points and these points are not evenly spread across the map. The distribution shown for caries experience and for fluoride levels provides a general rather than a detailed picture. Second, the data on caries experience may be subject to bias as they are based on those children who attend the school dental service and may not be representative of children in each community. There are no reliable data on the proportion of children examined in each community, and the proportion varies between communities. Third, the power of the study was limited by the number of communities for which data were available. Furthermore, those communities for which data were available may not have been representative of communities across the NT. Fourth, the assessment of the influence of other community level variables was limited by the scope and quality of the data available from the CHINS. Specifically, there were no data available for key known influences on caries experience such as dietary factors or oral hygiene that have been shown to be poor in these communities.[27] This study should not be seen to detract from the potential importance of other evidence-based oral health promotion activities.

Some factors for which there were data available and that showed associations with caries experience, may be proxies for other factors which were not included in the analysis rather than having a direct influence on caries experience themselves. For example, the association of less caries experience with a higher population percentage in temporary dwellings is a counter-intuitive funding. This could be explained by the proportion of people in temporary dwellings being a marker of other unmeasured or unknown social or environmental factors that have a positive influence on caries experience. Finally, the estimated effect of introducing fluoride is lower than the 50% to 60% estimates derived from historical data.[28] These lower estimates may be explained by the combined effect of the common exposure of children to other sources of fluoride (for example toothpaste, fluoridated processed foods and fluids) and imprecision in our estimates as a result of small numbers and uncontrolled confounders. While the historical data suggests our estimate of potential impact is on the low side, our estimates are closer to those observed in contemporary communities using the caries experience of teeth rather than tooth surfaces.[7,25,26]

Conclusion

From a population health perspective, the installation of fluoridation plants in communities with low levels of natural fluoride will result in much greater health gains in the form of improved oral health than might result from de-fluoridation plants to alleviate of the relatively innocuous effects of mild to moderate fluorosis experienced in a few NT communities. This is an issue that requires addressing in the Australian Drinking Water Guidelines (ADWG).

For the purpose of these guidelines, fluoride is classified as an 'impurity'. Associated health-related guideline values are intended to reflect the concentration "that, based on present knowledge, does not result in any significant risk to the health of the consumer over a lifetime of consumption".[23] A concentration of 1.5 mg/L is the maximum value for this parameter as recommended by the 2004 ADWG. However, the evidence is that lack of adequate levels of fluoride in water supplies could be regarded as a significant health risk. In terms of the numbers of people without adequate fluoride in their drinking water in remote communities in the NT and the prevalence and severity of dental caries, the risks of the inadequate levels in many communities far outweigh the risks of excessive fluoride in the water supplies of a few communities. The Australian Drinking Water Guidelines fail to provide any assessment of the relative risks to health of inadequate compared to excessive fluoride in water supplies, with a consequence that water authorities are pursuing expensive programs of de-fluoridation without a proportionate commitment to ensuring the effective implementation and operation of fluoridation plants in remote communities. The ADWG require revision to reflect the risk/benefit balance of fluoridation and de-fluoridation as a guide to water authorities for policy and prioritisation of resource allocation.

Large numbers of children affected by dental caries, the lack of fluoride in natural water supplies, poor socio-environmental conditions, lack of access to oral health services and poor dietary and oral hygiene practices all point to a requirement for strategic action on oral health. By mapping community-specific fluoride levels this study provides focused information to support strategic implementation of water fluoridation in communities in the NT in order to maximise population health impact. Ignoring investment in water fluoridation while increasing investment in dental services is to neglect a vitally important preventive intervention for oral health.

Implications

This study provides evidence to confirm fluoridation of water supplies as a priority intervention for addressing dental caries experienced by children in remote Indigenous communities in Australia.

The Australian drinking water guidelines require revision to reflect the risk/benefit balance of fluoridation and de-fluoridation as a guide to water authorities for policy and prioritisation of resource allocation.

Acknowledgements

Thanks to Frank Siciliano for generating the maps of fluoride levels and dental caries experience.

The project involved the cooperation of NT government agencies [Department of Community Development, Sport and Cultural Affairs (DCDSCA) and the Department of Health and Community Services (DHCS) the Power and Water Corporation (PWC)], as well as the Aboriginal and Torres Strait Islander Commission (ATSIC) and the University of Adelaide and Menzies School of Health Research. This project would not have been possible without the efforts of the DHCS staff in recording caries experience data as part of their service provision role to children in remote communities, and the AIHW DSRU for data collection, preparation and analysis. Finally, support for this project was received from an NHMRC Strategic Research Development Grant.

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