Community Dent Oral Epidemiol 2012; 40 (Suppl. 2): 55–64

Community Dentistry and Oral Epidemiology

Effectiveness of water fluoridation in caries prevention

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Rugg-Gunn AJ, Do L. Effectiveness of water fluoridation in caries prevention. Community Dent Oral Epidemiol 2012; 40 (Suppl. 2): 55–64. All rights reserved. © 2012 John Wiley & Sons A/S

Abstract – *Objectives:* To review the effectiveness of adjusted fluoridation of public water supplies in the prevention of dental caries, with emphasis on results of studies published worldwide since 1990 and to discuss aspects of the design and reporting of these studies compared with those published before 1990. *Method:* Studies published worldwide, in any language, reporting the effect of water fluoridation in terms of the dmf/DMF caries index between 1990 and 2010 were examined. The literature search was by professional Internet search, back-tracking from references given in publications, hand-searching all issues of four journals and by contacting colleagues in relevant countries. For the dmf index, age 5 year was preferred, and for the DMF index, age 12 year or older was preferred. The results were compared with results obtained from worldwide literature search prior to 1990 by the same author. *Results:* Fifty-nine studies of adjusted water fluoridation were identified, yielding 83 evaluations (30 recording dmft/s and 53 recording DMFT/S) from 10 countries. These numbers are lower than pre-1990 results of 113 studies (66 for primary and 86 for permanent teeth) from 23 countries. For the USA, for example, four studies were indentified since 1990 compared with 61 studies before 1990. The most number of recent reports came from Brazil and Australia. There were fewer reports of per cent caries reductions (% CR) above 50% in the recent studies. 86% of the post-1990 investigations were concurrent control cross-sectional studies and, of these, 52% used multivariate statistical analysis to adjust for confounding factors. In the eight studies that provided dmf/DMF data before and after adjustment for confounders, the % CR were little affected by these adjustments. *Conclusions:* Fewer studies have been published recently. More of these have investigated effect at the multi-community, state or even national level. The dmf/DMF index remains the most widely used measure of effect. % CR were lower in recent studies, and the 'halo' effect was discussed frequently. Nevertheless, reductions were still substantial. Statistical control for confounding factors is now routine, although the effect on per cent reductions tended to be small. Further thought is needed about the purpose of evaluation and whether measures of effect and study design are appropriate for that purpose.

Key words: dental caries; prevention; water fluoridation

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Submitted 1 March 2012;
accepted 15 June 2012

In 2007, the World Health Assembly (1, 2) told the world to implement water fluoridation where necessary and feasible: 'for countries without access to optimal levels of fluoride, and which have not yet established systematic fluoridation programmes, to consider the development and implementation of fluoridation programmes, giving priority to equitable strategies such as the automatic administration of fluoride, for example, in drinking-water, salt or milk, and to the provision of affordable fluoride toothpaste.' There is, in that statement, the implication, by the highest health authority, that water fluoridation is effective and safe. Currently, water fluoridation reaches about 350 million people worldwide (3). Coverage in Australia is now close to 90% of the population. There have been several authoritative reviews of water fluoridation, the latest being in Australia in 2007 (4). It concluded: 'The existing body of evidence strongly suggests that water fluoridation is beneficial at reducing dental caries'. Some issues relating to effectiveness will now be explored.

doi: 10.1111/j.1600-0528.2012.00721.x

There are several ways of quantifying the effect of water fluoridation: prevalence, severity, cost, quality of life and individual items of 'suffering' (for want of a better word). As the presence of caries at the cavitation stage is considered synonymous with need to treat by professional, prevalence is a useful indication of the proportion needing professional care. It hides, though, the size of the problem in the affected population and, being a proportion, is less useful statistically. The DMF index remains the best indicator of severity, being simple to record and amenable to more incisive statistical analysis. A DMF score above a certain threshold indicates those with a 'caries problem'. The last three, cost of disease prevented, enhancement of quality of life and reduction of 'suffering' have received sporadic attention, and the top two, prevalence and severity, have been by far the most commonly used methods for quantifying effect.

The size of the effect will be considered first. Chapter 5 in a book published in 1991 reviewed 'Community fluoridation schemes around the world' (5). This gathered together all publications of effectiveness of adjusted water fluoridation schemes up to that time, written in any language. One hundred and thirteen studies from 23 countries that provided DMF data are listed in Table 5.2 in the book, and the % CR recorded in these 113 studies was summarized in Figure 5.1. This figure has found its way into many publications, including those of WHO (6). The modal reduction for the 66 studies of primary teeth was 40–50%, and the modal reduction for the 86 studies of permanent teeth was 50–60%. Fifty-seven per cent of these studies were of a historical control design and the remainder were of a parallel control (or concurrent control) design; however, the pattern of % CR was the same for the two designs of study. A major aim of this publication was to update this information, draw conclusions and make recommendations.

Method

Literature published between 1990 and 2010 was searched to identify reports of studies into the effectiveness of water fluoridation. The search methods included a professional Internet literature search, back-tracking from references given in publications, hand-searching of each issue of four relevant journals and corresponding with colleagues in countries with water fluoridation. Water fluoridation had to be 'adjusted' to the optimum, and natural fluoridation information was excluded; fluoridation had to be continuous. Publications in any language were accepted. They had to be published in a scientific journal or government report and had to provide dmf or DMF data for fluoridated and nonfluoridated communities. For dmf, the age of 5 year, and for DMF, the age of 12 year or older were preferred. Information for continuous residents was preferred. These criteria were similar to those used in the previous publication (5). Information regarding data missing from publications was obtained from the authors or colleagues.

Results

Fifty-nine studies of adjusted water fluoridation, conforming to the above criteria, were identified, yielding 83 evaluations (30 for primary and 53 for permanent teeth), from 10 countries (Table 1). This compares with 113 studies yielding 152 evaluations (66 for primary and 86 for permanent teeth), from 23 countries before 1990 (5). There was a sharp drop in publications from the USA where there were 32 publications during the 1960s and 14 during the 1970s, compared with two during the 1990s and two during the 2000s. Post-1990, most studies came from Brazil and Australia with 13 studies each. Post-1990, there were more studies of adult age groups. Post-1990, there was a higher proportion of multi-community, state and national evaluations. While before 1990, 57% of studies were of historical (retrospective or self-) control design, post-1990, only 14% was of this design; the rest being concurrent (parallel) control designed studies. While prior to 1990, there was little difference between the % CR found in historical control and concurrent control studies (Tables 5.2 and 5.3 in (5)), higher % CR was recorded in historical design studies post-1990 (Fig. 1). Figure 2 presents the % CR obtained before and after 1990 for primary and permanent teeth separately. For primary teeth, while the modal score pre-1990 was 40–49% (24 evaluations), it was 30–59% (22 evaluations) post-1990. For permanent teeth, % CR was lower post-1990, the mode being 50–59% pre-1990 and 40–49 post-1990. The contribution of the 21 evaluations from Australia, post-1990, to the worldwide profile of % CRs is given in Fig. 3.

One marked change since 1990 has been the use of multivariate statistical analysis to adjust for

Table 1. Investigations into the effectiveness of adjusted fluoridation of public water supplies published worldwide 1990–2010

Country	F community	References	Year F began	Year of study	Age of subjects	Index	Non-F caries	% CR	Type of study
USA	National	Brunelle and Carlos (7)	Various	1986–1987	12	DMFS	2.97	17	X
	National	Brunelle and Carlos (7)	Various	1986–1987	17	DMFS	8.59	18	X
	Washington State	Grembowski et al. (8)	1956	1989	20–34	DFS	27.9	44	X adj
	Tennessee	Gillcrist et al. (9)	1951	1996–1997	5–11	dmfs	8.8	21	X adj
	Tennessee	Gillcrist et al. (9)	1951	1996–1997	5–11	DMFS	1.0	25	X adj
	NY State (upper)	Kumar et al. (10)	1956–1980	1997–1999	8	dmfs	4.18	14	X adj
Canada	Trois-Rivieres	Ismail et al. (11)	1977	1991	15–17[a]	DMFS	12.8	24	X
	Trois-Rivieres	Ismail et al. (11)	1977	1991	15–17[b]	DMFS	9.0	5	X
	Kentville	Ismail et al. (12)	1977	1991	11–12	DMFS	2.8	39	X
	Kelowna	Clark et al. (13)	1954	1991	6–14	DMFS	2.53	35	X
Argentina	Santa Fe	Brezina and Baranchuk (14)	1969	1978	10	DMFT	5.41	57	H
Brazil	Vitória	Cortes et al. (15)	1982	1994e	6–12	dmft	2.1	29	X adj
	Araraquara	Dini et al. (16)	1963	1995–1996	5–6	dmft	5.3	51	X
	Araraquara	Dini et al. (16)	1963	1995–1996	11–12	DMFT	2.8	18	X
	Pederneiras	Sales-Peres and Bastos (17)	1982	1998	12	DMFT	4.91[c]	11	X
	Sorocaba	Cypriano et al. (18)	1981	1998	5	dmft	5.5	49	X
	Sorocaba	Cypriano et al. (18)	1981	1998	12	DMFT	3.1	19	X
	São Paulo	Tagliaferro et al. (19)	1985	1998	12	DMFT	4.4	25	X
	Baixo Guandu	Saliba et al. (20)	1953	2002–2005	5	dmft	3.36	31	X
	Baixo Guandu	Saliba et al. (20)	1953	2002–2005	12	DMFT	3.38	54	X
	Baixo Guandu	Saliba et al. (20)	1953	2002–2005	15–19	DMFT	6.56	47	X
	Baixo Guandu	Saliba et al. (20)	1953	2002–2005	34–44	DMFT	20.12	31	X
	Bauru	Bastos et al. (21)	1975	2001	12	DMFT	9.89	85	H
	Baixo Guandu	Barros (1993)[d]	1953	1967	12	DMFT	8.61	69	H
	Belo Horizonte	Oliveira (1995)[d]	1975	1991	12	DMFT	7.95	33	H
	Paulínea	Moreira (1996)[d]	1980	1994	12	DMFT	3.4	53	H
	Piracicaba	Basting (1997)[d]	1971	1992	12	DMFT	8.60	44	H
	Vitória	Ferreira (1999)[d]	1982	1996	12	DMFT	9.3	84	H
	Santos	Sales Peres (2001)[d]	1983	1989	12	DMFT	8.9	43	H
UK	Newcastle	Murray et al. (23)	1969	1989–1990	15	DMFS	6.1	43	X
	Anglesey	Thomas and Kassab (24)	1955	1986–1987	18–32	DMFT	13.6	30	X
	Huddersfield	Booth et al. (25)	1970	1989	3	dmft	0.74	59	X
	Newcastle	Evans et al. (26)	1969	1994	5	dmfs	5.77	52	X
	Anglesey	Ellwood and O'Mullane (27)	1955	1991	14	DMFS	4.3	33	X adj
	Newcastle	Jones et al. (28)	1969	1992–1993	12	DMFT	1.46	43	X adj
	Newcastle	Jones et al. (29)	1969	1993–1994	5	dmft	1.9	44	X adj
	England (7 Districts.)	Riley et al. (30)	Various	1993–1994	5	dmft	1.8	52	X adj
	Cheshire	Tickle et al. (31)	1970	1997–1998	5	dmft	1.43	29	X adj
	England (national)	Foster et al. (32)	Various	2003–2004	5	dmft	1.58	46	X adj
	England (national)	Foster et al. (32)	Various	2004–2005	11	DMFT	0.67	33	X adj

Table 1 Continued

Country	F community	References	Year F began	Year of study	Age of subjects	Index	Non-F caries	% CR	Type of study
Ireland	Western Health B.	O'Mullane et al. (33)	1964–1974	1992	5	dmft	2.1	52	X
	Western Health B	O'Mullane et al. (33)	1964–1974	1992	12	DMFT	2.2	27	X
	North-Eastern H. B.	O'Mullane et al. (33)	1964–1974	1995	5	dmft	1.8	33	X
	North-Eastern H. B.	O'Mullane et al. (33)	1964–1974	1995	12	DMFT	1.6	19	X
	Ireland (national)	O'Mullane et al. (33)	1964–1974	1989–1990	16–24	DMFT	7.6	5	X
	Ireland (national)	Whelton et al. (34)	1964–1974	2001–2002	5	dmft	1.7	41	X adj
	Ireland (national)	Whelton et al. (34)	1964–1974	2001–2002	15	DMFT	3.2	34	X adj
	Ireland (national)	Whelton et al. (35)	1964–1974	2001–2002	5	dmft	1.8	44	X adj
	Ireland (national)	Whelton et al. (35)	1964–1974	2001–2002	15	DMFT	3.6	42	X adj
Israel	National	Zadik et al. (36), Kelman (37)	1984–1995	1989	5	dmft	3.89	55	X
	National	Zadik et al. (36), Kelman (37)	1984–1995	1989	12	DMFT	4.39	40	X
Korea	Ok-cheon	Kang et al. (38)	1997	2004	6	dft	4.13	59	H
	Yeoncheon	Park (39)	1981	2006	12	DMFT	4.13	41	X
	Nam-gu	Chin et al. (40)	1999	2005	5	dft	4.12	34	X
Australia	Melbourne	Brown et al. (41)	1977	1985	8	dmft	3.5	31	X
	Perth	Stockwell et al. (42)	1968	1987	5	dfs	2.18	17	X adj
	Perth	Stockwell et al. (42)	1968	1987	15	DFS	4.42	10	X adj
	Perth	Riordan (43)	1968	1989–1990	12	DMFT	1.57	43	X adj
	National	Morgan et al. (44)	Various	1988	15–19	DMFT	5.02	27	X
	National	Morgan et al. (44)	Various	1988	20–24	DMFT	8.32	49	X
	South Australia	Slade et al. (45)	1971	1991–1992	5	dmfs	3.18	43	X adj
	South Australia	Slade et al. (45)	1971	1991–1992	15	DMFS	2.70	0	X adj
	Townsville	Slade et al. (46)	1965	1991–1992	5	dmfs	2.98	55	X adj
	Townsville	Slade et al. (46)	1965	1991–1992	12	DMFS	1.80	48	X adj
	National	Hopcraft and Morgan (47)	Various	1996	17–35	DMFS	10.49	23	X adj
	National	Hopcraft and Morgan (48)	Various	2002–2003	17–51	DMFT	3.91	24	X adj
	National	Mahoney et al. (49)	Various	2006	17–24	DMFT	4.5	24	X adj
	National	Mahoney et al. (49)	Various	2006	25–34	DMFT	7.8	39	X adj
	National	Mahoney et al. (49)	Various	2006	35–44	DMFT	11.3	35	X adj
	Blue Mountains	Evans et al. (50)	1992	2003	6	dmft	1.96	68	H
	Blue Mountains	Evans et al. (50)	1992	2003	11	DMFT	1.02	68	H
	Hawkesbury	Evans et al. (50)	1998	2003	5	dmft	0.88	30	H
	National	Hopcraft et al. (51)	Various	2008	17–35	DMFT	3.87	25	X adj
	National, excl. NSW	Armfield (52)	Various	2002	5–10	dmft	2.33	29	X adj
	National, excl. NSW	Armfield (52)	Various	2002	8–15	DMFT	1.04	32	X adj
NZ			1966	1990	5	dmfs	4.41	66	X

Table 1 Continued

Country	F community	References	Year F began	Year of study	Age of subjects	Index	Non-F caries	% CR	Type of study
	Dunedin, Ashburton	Treasure and Dever (53)							
	Dunedin, Ashburton	Treasure and Dever (54)	1966	1990	14	DMFT	6.20	49	X adj
	Wellington	Lee and Dennison (55)	1965	1996	5	dmfs	3.80	31	X adj
	Wellington	Lee and Dennison (55)	1965	1996	12	DMFS	2.37	41	X adj
	Invercargill	Mackay and Thomson (56)	1963	2002	9	dmfs	5.11	33	X
	Invercargill	Mackay and Thomson (56)	1963	2002	9	DMFS	1.22	50	X adj
	Auckland	Kanagaratnam et al. (57)	1966	2007	9	dmft	2.42	31	X adj
	National	Ministry of Health (58)	Various	2009	18+	DMFT	15.7	10	X adj

X, cross-sectional study; H, historical (before & after) study;% CR, per cent caries reduction; adj, data adjusted for confounding factors by multivariate statistical analysis; e, estimated.
Only studies providing dmf/DMF information are included. Where data for several ages were given, age 5 year for dmf and age 12 year or older for DMF are listed.
[a]Public schools.
[b]Private schools.
[c]Averaged over municipalities.
[d]Quoted by Ramires and Buzalaf (22).

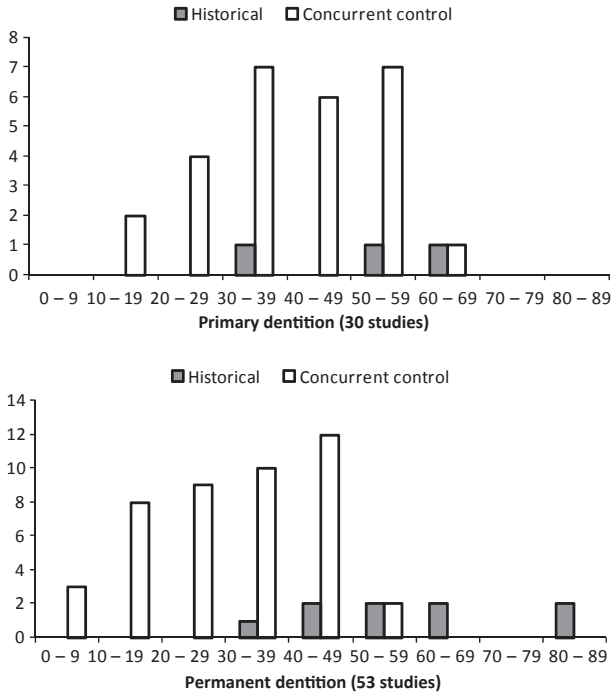

Fig. 1. Per cent caries reductions (% CR) recorded in post-1990 studies with historical control design or concurrent control design, for primary and permanent teeth.

confounding factors – 52% of the 71 concurrent control evaluations (45% of all 83 evaluations) did this – because of the enormous growth in computing power. Prior to 1990, findings were often presented for each social group separately. Post-1990, presentation of control for confounding factors has taken two forms. First, the statistical significance of the effect of water fluoridation has been adjusted, but not the dmf/DMF data or the % CR; and, second, the statistical significance of effect and the size

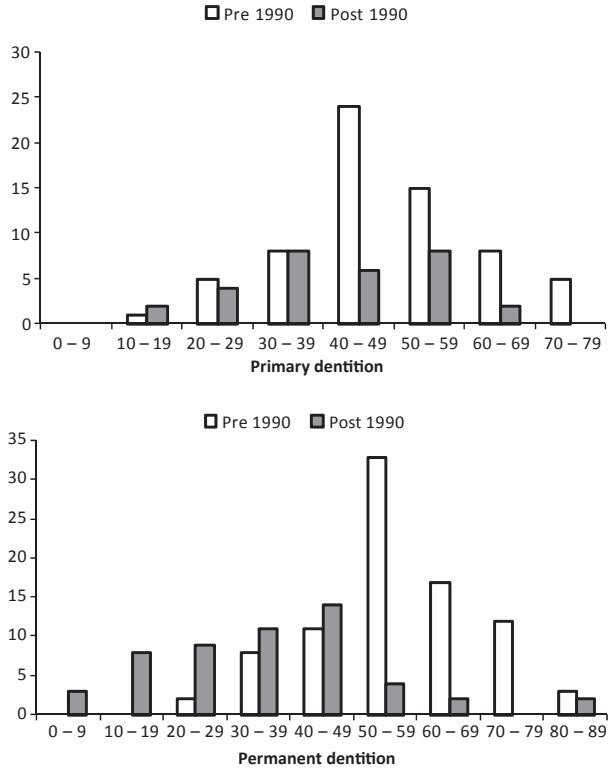

Fig. 2. Per cent caries reductions obtained in 113 studies pre-1990 (5) and 59 studies post-1990 (Table 1), for primary and permanent teeth.

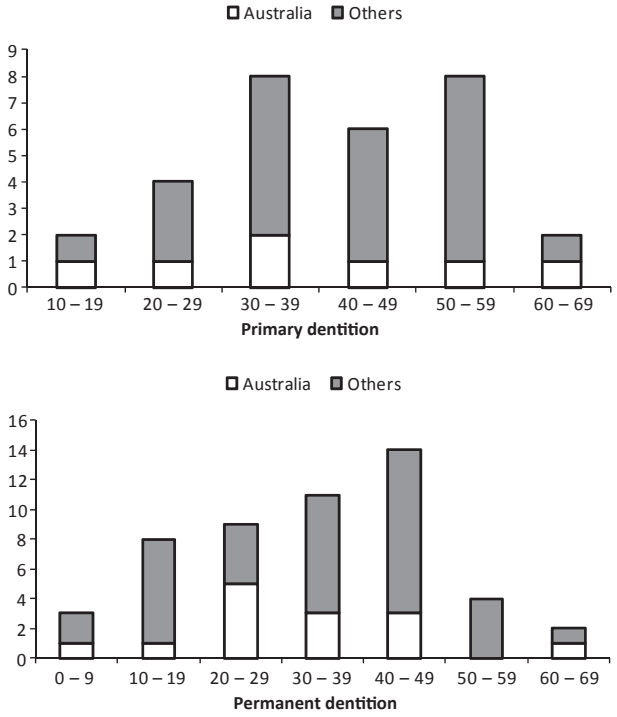

Fig. 3. The contribution of the 21 Australian evaluations to the worldwide profile of per cent caries reductions (% CR) published post-1990, for primary and permanent teeth.

of effect have been adjusted. Impressive publications on this topic come from the UK (29) and Australia (46–49, 51). In the 2009 New Zealand national survey (58) where the effect of water fluoridation at a national level was presented, data were controlled for several known confounding factors. Figure 4 presents % CRs for the post-1990 evaluations where adjustment to the statistical significance of

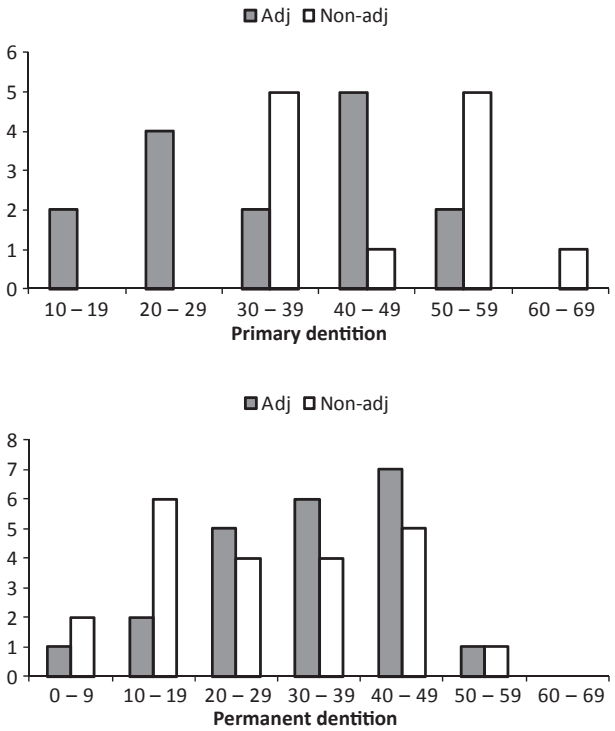

Fig. 4. Per cent caries reductions (% CR) recorded in concurrent design post-1990 studies where adjustment to the statistical significance of effect of water fluoridation was present or absent, for primary and permanent teeth.

the effect of water fluoridation was present or absent, for primary and permanent teeth separately. While there was little difference in the profiles for permanent teeth, a sharp difference in profile was observed for primary teeth.

Of the 37 evaluations that presented adjusted statistical significance, 15 presented adjusted % CRs. Of these 15, eight gave data both before and after multivariate adjustment for confounding factors (Table 2). Overall, there was no great change in the % CRs after adjustment compared with before adjustment: in five, there was a slight reduction, while in two, there was a slight increase. The exception is the New Zealand national survey (58) – the report states strongly, though, that the people surveyed were not continuous residents and not necessarily with continuous exposure – a similar situation to the 1990 analysis of the effect of water fluoridation nationally in the USA (7).

One study does not fit into the above analysis of cross-sectional caries experience studies. That is the 3-year caries increment Australian study published in 2008 (59). Caries increments were substantially higher in primary teeth of children not exposed to water fluoridation in South Australia and Queensland and also in the permanent teeth of children in Queensland.

Discussion

The information given in Table 1 came from studies published in scientific literature or national reports. While information from nonfluoridated control

Table 2. Per cent caries reductions obtained from eight publications that provided these data before and after adjustment by multivariate analysis for the effect of confounding factors

Authors	Age (year)	Before adjustment	After adjustment
Slade et al. (46)	5–12	'Virtually identical'	Parameter estimates
Jones et al. (29)	5	43	44
Kumar et al. (10)	8	15	14
Hopcraft and Morgan (47)	17–35	26	23
Hopcraft and Morgan (48)	17–51	28	24
Mahoney et al. (49)	17–56	27	24
Hopcraft et al. (51)	17–35	22	25
NZ National Survey (58)	18+	22	10

communities was required, the quality of studies was not judged with respect to 'blinding' of examiners and prefluoridation data for concurrent control studies (60). This allowed comparisons with the pre-1990 data (5) to be made on equal footing.

Conclusions from the comparisons of data collected before 1990 (5) and after 1990 (Table 1) include the following. First, there were fewer recent studies compared with the heydays in the 1960s and 1970s. This is especially true of the USA. There were no studies from several countries with ongoing water fluoridation programmes. While this may be understandable from countries such as Singapore and Hong Kong SAR China with 100% water fluoridation, other countries have less extensive coverage.

Second, the type of study has changed. Studies published during the last 20 years have been dominated by cross-sectional, concurrent control design where recording and statistical control for confounding factors are routine. The dmf/DMF index remains the most common measure of effect. There have been fewer single-community studies and more evaluations of effect on a state or subnational scale. These are exemplified by studies in the USA (7), UK (30, 32), Ireland (33–35), Israel (36, 37), Australian Statewide studies (45, 46, 52) and the New Zealand national study (58). There is a mix, though, of studies that have restricted analysis to continuous residents and those that have not – in this respect, the purpose of the study needs to be stated clearly. Those studies that have provided results for both categories show clearly the effect increasing with per cent of life exposed to fluoridated water (45, 46). All the above analyses have been restricted to water supplies with adjusted fluoride concentration, at or near the optimum. Post-1990, there has been a growing number of studies of the effectiveness of water fluoridation on adult dental health, which was not possible before 1990. These have been conducted in the USA (8), Brazil (20), UK (24), Ireland (33), Australia (44, 47–49, 51) and New Zealand (58). While it has been traditional to report the effect of fluoridating, a recent Australian article reported the effect of not fluoridating public water supplies (52).

Third, the measured effect is smaller post-1990 than it was in the earlier studies. This has been well described as the halo or diffusion effect in the USA (7) and more recently in Australia. This was exemplified in a 1995 paper (45) where a clear effect of fluoridation was recorded in Queensland (where 5% receive fluoridated water), and a small statistically non-significant effect was recorded in South Australia (with over 70% receiving fluoridated water). The South Australian children without fluoridated water had lower caries experience than their counterparts in Queensland. The authors concluded that the diffusion effect in South Australia must be substantial. Fourth, recent analyses have almost routinely been adjusted for known confounding factors. While this is right and proper, the magnitude of the effect of water fluoridation appears to be little changed in most studies. The York systematic review (60) insisted that studies must have prefluoridation data in study and control communities: very few of these post-1990 studies did so. Blind assessment of disease is urged, but few if any studies did so. While confounding factors are recorded, the relative importance of each confounder is less clear: a disadvantage is that such information may be rather country specific.

Measurement of effect has almost routinely been caries prevalence and severity. Multivariate analysis has resulted in effect being expressed as odds ratios or similar. One may ask why is the study being undertaken and who is most interested in the findings. Many decisions to fluoridate or continue fluoridation are made by lay people. They might be more interested in reduction in 'suffering', such as the occurrence of abscesses, toothache, general anaesthetics for tooth extraction and cost (Table 3; 61), rather than DMF, odds ratios, relative risk or QALYs. Or are decisions made by public health experts who expect competent analyses? Or are they made by politicians more interested in equity?

So in summary, a review of literature over the past 20 years has found fewer studies from fewer countries. These studies are no longer single-community studies. Almost all are now concurrent control cross-sectional studies. Recording and statistical handling of confounding factors has improved

Table 3. The effect of water fluoridation in 5-year-old children in Newcastle and Northumberland, UK (61) on the occurrence of dental abscesses, toothache, general anaesthetics for tooth extraction and cost (GB£, 1976)

	Fluoridated	Nonfluoridated
% With 1 + abscesses	0%	5%
% Ever had toothache	17%	38%
% Ever had GA for dental extraction	7%	22%
Cost of treatment already completed	£1.27	£1.63
Cost of treatment still required	£1.93	£7.89

greatly. Caries reductions are less than recorded pre-1990, but are still substantial. There is need for further thought to strengthen study design and measurements of effect. This review has considered the prevention of dental caries, and other aspects, such as dental fluorosis, have not been considered.

Acknowledgements

We wish to thank the following for providing information on evaluations of water fluoridation: Marília Buzalaf, Sheila Jones, Jay Kumar, Michael Lennon, Edward Lo, Dai-il Paik, Philip Schluter, Harold Sgan-Cohen, Murray Thomson and Alberto Villa.

Conflicts of interest

The authors have no conflicts of interest to declare.

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