A Systematic Review of Public Water Fluoridation

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September 2000

ISBN 1 900640 16 3

This report can be ordered from: Publications Office, NHS Centre for Reviews and Dissemination, University of York, York YO10 5DD. Telephone 01904 433648; Facsimile: 01904 433661: email: crdpub@york.ac.uk
Price £20

The NHS Centre for Reviews and Dissemination is funded by the NHS Executive and the Health Departments of Wales and Northern Ireland. The views expressed in this publication are those of the authors and not necessarily those of the NHS Executive or the Health Departments of Wales or Northern Ireland.

Printed by York Publishing Services Ltd.

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ACKNOWLEDGEMENTS

The review team gratefully acknowledges the invaluable contributions of the members of the Advisory Board: The Earl Baldwin of Bewdley, House of Lords; Sir Iain Chalmers, UK Cochrane Centre; Dr. Sheila Gibson, Glasgow Homeopathic Hospital; Ms. Sarah Gorin, Help for Health Trust; Professor MA Lennon, Department of Clinical Dental Sciences, University of Liverpool School of Dentistry, Chairman of the British Fluoridation Society; Dr. Peter Mansfield, Director of Templegarth Trust; Professor JJ Murray, Dean of Dentistry, University of Newcastle; Mr. Jerry Read, Department of Health; Dr. Derek Richards, Centre for Evidence-Based Dentistry; Professor George Davey Smith, Department of Social Medicine, University of Bristol; Ms. Pamela Taylor, Water UK.

Special thanks to Professor Trevor Sheldon, Department of Health Studies, University of York, who chaired the Advisory Board.

The team also acknowledges Dr. Keith Abrams, University of Leicester for commentary on the analysis, Marijke Van Gestel for assistance in the early stages of the review, and Vanda Castle for secretarial support.

Thanks to Dr. Alan Glanz from the Department of Health for efficient collaboration on the organisational aspects of the project.

We also greatly appreciate the contributions of many scientists and members of the public who submitted papers for inclusion and made valuable comments about the protocol, data extraction tables and results of the review.

EXECUTIVE SUMMARY

This systematic review has been commissioned by the Chief Medical Officer of the Department of Health to 'carry out an up to date expert scientific review of fluoride and health' (Paragraph 9.20, Our Healthier Nation).

Overall, the aim has been to assess the evidence on the positive and negative effects of population wide drinking water fluoridation strategies to prevent caries. To achieve this aim five objectives were identified:

Objective 1: What are the effects of fluoridation of drinking water supplies on the incidence of caries?

Objective 2: If water fluoridation is shown to have beneficial effects, what is the effect over and above that offered by the use of alternative interventions and strategies?

Objective 3: Does water fluoridation result in a reduction of caries across social groups and between geographical locations, bringing equity?

Objective 4: Does water fluoridation have negative effects?

Objective 5: Are there differences in the effects of natural and artificial water fluoridation?

Methods

A search of 25 electronic databases (with no language restrictions) and the world-wide-web was undertaken. Relevant journals and indices were hand searched and attempts were made to contact authors for further information.

Quality inclusion criteria were based on a pre-defined hierarchy of evidence (A, B, and C). Studies of efficacy were included if they were of evidence level A or B. In order to allow the broadest search for evidence on potential adverse effects, studies of all levels of evidence were included. Objective specific inclusion criteria, based on selection of participants, intervention, outcomes assessed, and study design appropriate for a given objective were then applied. Study validity was formally assessed using a published checklist modified for this review (CRD Report 4, 1996).

Inclusion criteria were assessed independently by at least two reviewers. Extraction of data from, and validity assessment of, included studies was independently performed by two reviewers, and checked by a third reviewer. Disagreements were resolved through consensus.

Where the data were in a suitable format, measures of effect and 95% confidence intervals (CI) were plotted. Heterogeneity was investigated by visual examination and statistically using the Q-statistic. Where no evidence of heterogeneity was found a meta-analysis was conducted to produce a pooled estimate of the measure of effect. Statistically significant heterogeneity was investigated using meta-regression. Multiple regression analysis was used to explore the relationship between fluoridation and fluorosis.

Results

214 studies met full inclusion criteria for one or more of the objectives. No randomised controlled trials of the effects of water fluoridation were found. The study designs used included 45 'before and after' studies, 102 cross-sectional studies, 47 ecological studies, 13 cohort (prospective or retrospective) studies and 7 case-control studies. Several studies were reported in multiple papers over a number of years.

Results by Objective

Objective 1

A total of 26 studies of the effect of water fluoridation on dental caries were found. For this objective, the quality of studies found was moderate (no level A studies). A large number of studies were excluded because they were cross-sectional studies and therefore did not meet the inclusion criteria of being evidence level B or above. All but three of the studies included were before-after studies, two included studies used prospective cohort designs, and one used a retrospective cohort design. All before-after studies located by the search were included. The most serious defect of these studies was the lack of appropriate analysis. Many studies did not present an analysis at all, while others only did simple analyses without attempting to control for potentially confounding factors. While some of these studies were conducted in the 1940's and 50's, prior to the common use of such analyses, studies conducted much later also failed to use methods that were commonplace at the time of the study.

Another defect of many studies was the lack of any measure of variance for the estimates of decay presented. While most studies that presented the proportion of caries-free children contained sufficient data to calculate standard errors, this was not possible for the studies that presented dmft/DMFT scores. Only four of the eight studies using these data provided estimates of variance.

The best available evidence suggests that fluoridation of drinking water supplies does reduce caries prevalence, both as measured by the proportion of children who are caries free and by the mean change in dmft/DMFT score. The studies were of moderate quality (level B), but of limited quantity. The degree to which caries is reduced, however, is not clear from the data available. The range of the mean difference in the proportion (%) of caries-free children is -5.0 to 64%, with a median of 14.6% (interquartile range 5.05, 22.1%). The range of mean change in dmft/DMFT score was from 0.5 to 4.4, median 2.25 teeth (interquartile range 1.28, 3.63 teeth). It is estimtaed that a median of six people need to receive fluoridated water for one extra person to be caries-free (interquartile range of study NNTs 4, 9). The best available evidence from studies following withdrawal of water fluoridation indicates that caries prevalence increases, approaching the level of the low fluoride group. Again, however, the studies were of moderate quality (level B), and limited quantity. The estimates of effect could be biased due to poor adjustment for the effects of potential confounding factors.

Objective 2

To address this objective, studies conducted after 1974 were examined. While only nine studies were included for Objective 2, these would have been enough to provide a confident answer to the objective's question if the studies had been of sufficient quality. Since these studies were completed after 1974, one might expect that the validity assessments would be higher than the earlier studies following the introduction of more rigorous study methodology and analytic techniques. However, the average validity checklist score and level of evidence was essentially the same for studies after 1974 as those conducted prior to 1974. Hence, the ability to answer this objective is similar to that in Objective 1.

In those studies completed after 1974, a beneficial effect of water fluoridation was still evident in spite of the assumed exposure to non-water fluoride in the populations studied. The meta-regression conducted for Objective 1 confirmed this finding.

Objective 3

No level A or B studies examining the effect of water fluoridation on the inequalities of dental health between social classes were identified. However, because of the importance of this objective, level C studies conducted in England were included. A total of 15 studies investigating the association of water fluoridation, dental caries and social class in England were identified. The quality of the evidence of the studies was low, and the measures of social class that were used varied. Variance data were not reported in most of these studies, so a statistical analysis was not undertaken.

There appears to be some evidence that water fluoridation reduces the inequalities in dental health across social classes in 5 and 12 year-olds, using the dmft/DMFT measure. This effect was not seen in the proportion of caries-free children among 5 year-olds. The data for the effects in children of other ages did not show an effect. The small quantity of studies, differences between these studies, and their low quality rating, suggest *caution* in interpreting these results.

Objective 4

DENTAL FLUOROSIS

Dental fluorosis was the most widely and frequently studied of all negative effects. The fluorosis studies were largely cross-sectional designs, with only four before-after designs. Although 88 studies of fluorosis were included, they were of low quality. The mean validity score for fluorosis was only 2.8 out of 8. All, but one, of the studies were of evidence level C. Observer bias may be of particular importance in studies assessing fluorosis. Efforts to control for the effects of potential confounding factors, or reducing potential observer bias were uncommon.

As there may be some debate about the significance of a fluorosis score at the lowest level of each index being used to define a person as ‘fluorosed’, a second method of determining the proportion ’fluorosed’ was selected. This method describes the number of children having dental fluorosis that may cause ‘aesthetic concern’.

With both methods of identifying the prevalence of fluorosis, a significant dose-response relationship was identified through a regression analysis. The prevalence of fluorosis at a water fluoride level of 1.0 ppm was estimated to be 48% (95% CI 40 to 57) and for fluorosis of aesthetic concern it was predicted to be 12.5% (95% CI 7.0 to 21.5). A very rough estimate of the number of people who would have to be exposed to water fluoride levels of 1.0 ppm for one additional person to develop fluorosis of any level is 6 (95% CI 4 to 21), when compared with a theoretical low fluoride level of 0.4 ppm. Of these approximately one quarter will have fluorosis of aesthetic concern, but the precision of these rough estimates is low. These estimates only apply to the comparison of 1.0 ppm to 0.4 ppm, and would be different if other levels were compared.

BONE FRACTURE AND BONE DEVELOPMENT PROBLEMS

There were 29 studies included on the association between bone fracture and bone development problems and water fluoridation. Other than fluorosis, bone effects (not including bone cancers) were the most studied potential adverse effect. These studies had a mean validity score of 3.4 out of 8. All but one study were of evidence level C. These studies included both cohort and ecological designs, some of which included analyses controlling for potential confounding factors. Observer bias could potentially play a role in bone fracture studies, depending on how the study is conducted.

The evidence on bone fracture can be classified into hip fracture and other sites because there are more studies on hip fracture than any other site. Using a qualitative method of analysis (Figure 8.1), there is no clear association of hip fracture with water fluoridation. The evidence on other fractures is similar. Overall, the findings of studies of bone fracture effects showed small variations around the ‘no effect’ mark. A meta-regression of bone fracture studies also found no association with water fluoridation.

CANCER STUDIES

There were 26 studies of the association of water fluoridation and cancer included. Eighteen of these studies are from the lowest level of evidence (level C) with the highest risk of bias.

There is no clear association between water fluoridation and overall cancer incidence and mortality. This was also true for osteosarcoma and bone/joint cancers. Only two studies considered thyroid cancer and neither found a statistically significant association with water fluoridation.

Overall, no clear association between water fluoridation and incidence or mortality of bone cancers, thyroid cancer or all cancers was found.

OTHER POSSIBLE NEGATIVE EFFECTS

A total of 33 studies of the association of water fluoridation with other possible negative effects were included in the review. Interpreting the results of studies of other possible negative effects is very difficult because of the small numbers of studies that met inclusion criteria on each specific outcome, and poor study quality. A major weakness of these studies generally was failure to control for any confounding factors.

Overall, the studies examining other possible negative effects provide insufficient evidence on any particular outcome to permit confident conclusions. Further research in these areas needs to be of a much higher quality and should address and use appropriate methods to control for confounding factors.

Objective 5:

The assessment of natural versus artificial water fluoridation effects is greatly limited due to the lack of studies making this comparison. Very few studies included both natural and artificially fluoridated areas, and direct comparisons were not possible for most outcomes. No major differences were apparent in this review, however, the evidence is not adequate to make a conclusion regarding this objective.

Conclusions

This review presents a summary of the best available and most reliable evidence on the safety and efficacy of water fluoridation.

Given the level of interest surrounding the issue of public water fluoridation, it is surprising to find that little high quality research has been undertaken. As such, this review should provide both researchers and commissioners of research with an overview of the methodological limitations of previous research conducted in this area.

The evidence of a benefit of a reduction in caries should be considered together with the increased prevalence of dental fluorosis. The research evidence is of insufficient quality to allow confident statements about other potential harms or whether there is an impact on social inequalities. This evidence on benefits and harms needs to be considered along with the ethical, environmental, ecological, costs and legal issues that surround any decisions about water fluoridation. All of these issues fell outside the scope of this review.

Any future research into the safety and efficacy of water fluoridation should be carried out with appropriate methodology to improve the quality of the existing evidence base.

1. BACKGROUND

This review has been commissioned by the Chief Medical Officer of the Department of Health to 'carry out an up to date expert scientific review of fluoride and health' (Paragraph 9.20, Our Healthier Nation). The original objective given to the review team by the Department of Health was to conduct a systematic review of the efficacy and safety of water fluoridation. The protocol, including specific objectives, was then written by the review team, with the consultation and agreement of the advisory panel and in discussion with the Department of Health. The review agreed upon was a review of human epidemiological studies of water fluoridation.

The impact of fluoridation of drinking water supplies depends on a number of major issues: the potential benefits (including improved dental health and reductions in dental health inequalities); the potential benefits over and above that offered by the use of alternative interventions and strategies (e.g. fluoridated toothpaste); and the potential harms (including dental fluorosis, bone fractures and bone development problems, genetic mutations, birth defects, cancer and hypersensitivity).

This study aims to provide a systematic review of the best available evidence on potential positive and negative effects in order to assess the effects of water fluoridation. Decisions on artificial water fluoridation of course need to examine ethical issues, environmental and ecological impacts, cost and legal issues. These considerations are outside the scope of this review.

Systematic reviews locate, appraise and synthesise evidence from scientific studies in order to provide informative empirical answers to scientific research questions. They are therefore valuable sources of information for decision-makers. Systematic reviews differ from other types of review in that they adhere to a strict scientific design with the aims of making them more comprehensive, minimising the chance of bias and improving reliability. The intention is that a systematic review, rather than reflecting the views of authors or being based on only (a possibly biased) selection of the published literature, will contain a comprehensive assessment and summary of the available evidence. (For further information on systematic review methodology, see NHS Centre for Reviews and Dissemination Report 4 1996 and Sutton 1998.)

The history of health technology development shows that there have been numerous new interventions that were promising (or harmful) in animal and laboratory studies that turned out to be ineffective (or safe) when tested in humans. One example would be the drug omeprazole (Losec®) which caused gastric tumours in pre-clinical animal studies. However, such tumours have not been documented in humans, even in patients with conditions that require continuous treatment for many years. In general, when human data are available, animal or laboratory data provide far less reliable estimates of effect and, as such, do not bear significant weight on decisions about interventions. Such data will not be considered in this review.

A variety of study designs can be used to assess the effectiveness of a population-based intervention such as water fluoridation. These range from simple descriptive studies (e.g. cross-sectional), to studies of correlation at the population level (e.g. ecological studies), to studies of individual-based associations (e.g. case-control, before-after, and cohort studies) to formal experiments (e.g. randomised controlled trials).

The randomised controlled trial randomising individuals to fluoridated or non-fluoridated water would be the gold standard. However, studying the effects of water fluoridation poses problems for the use of the randomised controlled trial design. Water fluoridation affects population groups and it is thus difficult to randomly assign individuals to receive either fluoridated or non-fluoridated water. An alternative would be to randomise communities to fluoridated or non-fluoridated water. The fact that whole populations are either exposed or not exposed also poses a problem for cohort and case-control studies. Comparing exposures and outcomes between different population groups may cause problems as the two populations may differ with respect to other exposures or characteristics and so a causal relationship between the observed exposure and outcomes cannot be assumed. In observational studies (e.g. other than a randomised controlled trial) many people know whether or not a water supply is fluoridated and so blinding would not be possible, thus risking bias in observations.

Some possible adverse effects of water fluoridation may take many years to develop and so unless a study is specifically designed to investigate the relationship of these outcomes to fluoridation the relationship may go undetected. An assessment of the effectiveness of fluoridation on the incidence of caries is difficult because there are a number of factors that may influence caries prevalence other than fluoride in water, and these have changed over time. These factors include the introduction of fluoridated toothpaste, mouth rinses and improved dental hygiene in general. Traditional reviews of the literature tend to ignore the variable quality of studies and are therefore unlikely to present a reliable summary. Ideally, systematic reviews concentrate on studies that provide the strongest evidence, but where only a few good studies are available weaker designs may have to be considered.

Existing reviews do not address the major issues of benefit and harm in conjunction and in a systematic manner, as this review aims to do. The explicit methods used in this systematic review will limit bias through the use of specific inclusion criteria, and a formal assessment of the quality and reliability of the studies reviewed. The use of meta-analysis will increase statistical power and thus the precision of estimates of treatment effects and exposure risks. Finally, this review attempts to generate new questions and identify gaps in the research evidence.

1.1 Purpose

The aim of this systematic review is to assess the evidence on the positive and negative effects of population-wide drinking water fluoridation strategies to prevent caries. To achieve this aim five objectives have been identified:

Objective 1: What are the effects of fluoridation of drinking water supplies on the incidence of caries?

Objective 2: If water fluoridation is shown to have beneficial effects, what is the effect over and above that offered by the use of alternative interventions and strategies?

Objective 3: Does water fluoridation result in a reduction of caries across social groups and between geographical locations, bringing equity?

Objective 4: Does water fluoridation have negative effects?

Objective 5: Are there differences in the effects of natural and artificial water fluoridation?

2. METHODS

A diagram illustrating the stages of this systematic review's methods is presented in Figure 2.1.

2.1 Search strategy

2.1.1 Preliminary search

A preliminary search was undertaken to provide information on available reviews of fluoridation and to estimate the potential size of the research evidence on the effects of fluoride supplementation of drinking water. The preliminary search was carried out in several stages:

- Identification and collection of reviews of fluoridation.
- Medline search using a methodology filter strategy to identify the scope of the systematic reviews and meta-analyses literature (date range 1966 - 03/1999).
- Medline and Embase searches using a methodology filter strategy to identify primary studies including any randomised trials. (Medline date range 1966 - 05/1999; Embase date range 1980 – 05/1999).

The Medline and Embase databases were both searched using WinSpirs/SilverPlatter software. Further details about the preliminary search process are given in Appendix B, Section 1. The preliminary search strategy to retrieve systematic review and meta-analyses literature is included in Appendix B, Section 3.

2.1.2 Electronic database search

The full search built on the preliminary search strategies and involved searching a wide range of medical, political and environmental/scientific databases to identify primary studies. Each database was searched from its starting date to June/October 1999 (due to the number of databases, searches were carried out over a four month period). A list of the databases searched at each stage of the review and the dates searched are given in Appendix B, Section 2. Full details of all the strategies used in this review are given in Appendix B, Section 4. The databases searched were as follows:

- Medline
- Embase
- NTIS (National Technical Information Service)
- Biosis
- Current Contents Search (Science Citation Index and Social Science Citation Index)
- Healthstar (Health Service Technology, Administration and Research)
- HSRProj
- TOXLINE
- Chemical Abstracts
- OldMedline
- CAB Health
- FSTA (Food Science and Technology Abstracts)
- JICST- E Plus (Japanese Science and Technology)
- Pascal
- EI Compendex (Engineering Index)
- Enviroline
- PAIS (Public Affairs Information Services)
- SIGLE (System for Information on Grey Literature in Europe)
- Conference Papers Index
- Water Resources Abstracts
- Agricola (Agricultural Online Access)
- Waternet
- AMED (Allied and Complementary Medicine Database)
- Psyclit
- LILACS (Latin American and Caribbean Health Sciences Literature)

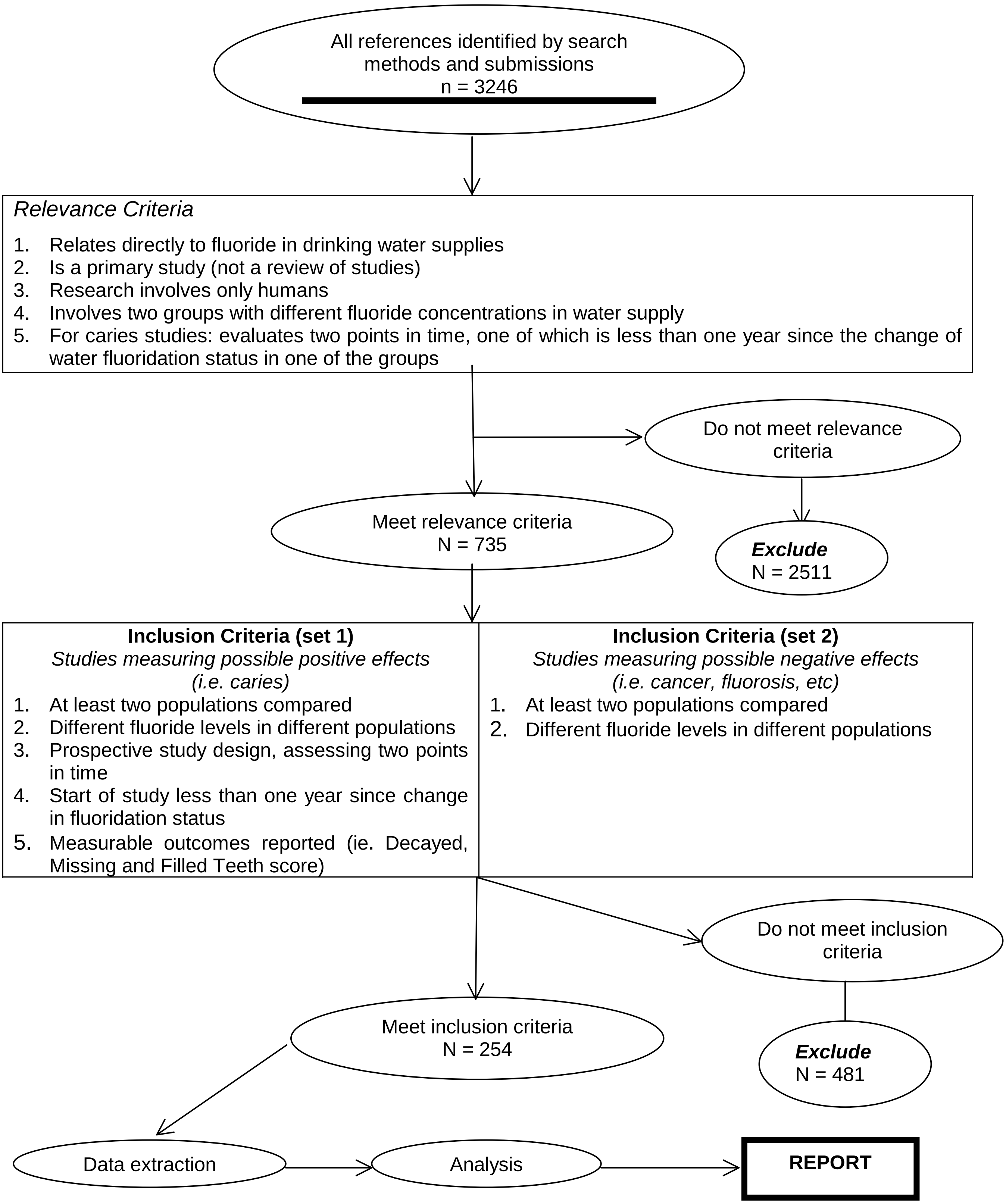

Figure 2.1 Review methods

2.1.3 Other searching

The World Wide Web was searched for web pages maintained by others interested in the issue of water fluoridation. A web page was designed and maintained by the NHS Centre for Reviews and Dissemination, University of York to inform the public on the purpose, methods and progress of the review. The web site included an e-mail response to enable members of the public and other organisations to submit articles for consideration. In addition to numerous individuals, examples of organisations that submitted lists of references are the National Pure Water Association and the British Fluoridation Society. Furthermore, advisory board members were asked to submit references or reports.

2.1.4 Hand searches

Hand searching of Index Medicus and Excerpta Medica was undertaken. Index Medicus was searched from 1959 back to 1945; Excerpta Medica was searched from 1973 back to 1955. A further sample of studies published before 1945 was retrieved from Index Medicus and Excerpta Medica and established that further searching was not required. Appendix B, Section 3 provides a list of search terms used in this hand searching process. The bibliographies of the eligible papers were also hand searched. Attempts were made to contact authors for further information if necessary. Further information about studies done in the UK was sought and obtained through the Public Records Office.

2.1.5 Updating the search

Update searches were undertaken at the beginning of February 2000. In order to identify the most useful databases, the included studies were examined to determine which of the above resources yielded the most studies included. Medline, Embase, Toxline and the Current Contents (Science Citation Index) were identified in this manner and included in the update search process.

2.1.6 Management of references

As such a wide range of databases had been searched, some degree of duplication of references resulted. In order to manage this issue, the titles and abstracts of the bibliographic records retrieved were downloaded and imported into Endnote (ISI ReSearch Soft, USA) reference management software to remove duplicate records.

2.2 Inclusion criteria

2.2.1 Methodological and quality criteria

Groups exposed or not exposed to fluoride may differ in respect to factors other than fluoride exposure itself. Some of these differences may be related to the outcomes under investigation (level of tooth decay, dental fluorosis, fractures etc) and so will confound any observed relationship and thus should be controlled for in the analysis. Confounding factors are factors that can cause or prevent the outcome of interest. In the case of water fluoridation these are likely to include age, gender, ethnicity, other sources of fluoridation and social class. Factors likely to modify the effect of fluoride on the outcomes under investigation, such as the level of tooth decay or delayed tooth eruption in the population before the introduction of fluoridation should also be considered.

Another important factor to be taken into account in assessing the effects of water fluoridation is blinding of outcome assessment. Blinding should be used to protect against the possibility that knowledge of participant's exposure to water fluoridation may affect the ways in which the investigators assess outcomes. Knowledge of outcomes may also affect assessment of fluoridation status and other factors in retrospective studies.

The following methodological issues were considered when assessing studies for inclusion: selection, confounding, and measurement. Study designs are often graded hierarchically according to their quality, or degree to which they are susceptible to bias. The hierarchy indicates which studies should be given most weight in a synthesis. In this review, the degree to which each study dealt with the methodological issues was graded into three levels of evidence:

LEVEL A (HIGHEST QUALITY OF EVIDENCE, MINIMAL RISK OF BIAS)

- Prospective studies that started within one year of either initiation or discontinuation of water fluoridation and have a follow up of at least two years for positive effects and at least five years for negative effects.
- Studies either randomised or address at least three possible confounding factors and adjust for these in the analysis where appropriate.
- Studies where fluoridation status of participants is unknown to those assessing outcomes.

LEVEL B (EVIDENCE OF MODERATE QUALITY, MODERATE RISK OF BIAS)

- Studies that started within three years of the initiation or discontinuation of water fluoridation, with a prospective follow up for outcomes.
- Studies that measured and adjusted for less than three but at least one confounding factor.
- Studies in which fluoridation status of participants was known to those assessing primary outcomes, but other provisions were made to prevent measurement bias.

LEVEL C (LOWEST QUALITY OF EVIDENCE, HIGH RISK OF BIAS)

- Studies of other designs (e.g. cross-sectional), prospective or retrospective, using concurrent or historical controls, that meet other inclusion criteria.
- Studies that failed to adjust for confounding factors.
- Studies that did not prevent measurement bias.

Studies meeting two of the three criteria for a given evidence level were assigned the next level down. For example, if a study met the criteria for prospective design and blinding for level A, but was neither randomised nor controlled for three or more potential confounding factors, it was assigned level B. Evidence rated below level B was not considered in our assessment of positive effects. However, this restricted assessment of the evidence for Objective 3, so the best level of evidence relevant to this objective (from any study design) was included. In our assessment of possible negative effects, all levels of evidence were considered. Adjustment for confounding factors required analysis of data, simply stating that two study groups were similar on noted confounding factors was not considered adequate.

2.2.2 Objective specific criteria

Specific inclusion criteria for each objective were based on the participants, intervention, outcomes measured and overall design of the study. All criteria were defined before the studies were assessed and were based on criteria commonly applied when critically appraising community based interventions (Elwood 1998). This review is limited to studies investigating the effects of water fluoridation on human populations. The objective-specific criteria for inclusion based on study design were:

OBJECTIVE 1. DOES FLUORIDATION OF DRINKING WATER SUPPLIES PREVENT CARIES?

Participants:

- Populations receiving fluoridated water (naturally or artificially)
- Populations receiving non-fluoridated water

Intervention:

- A change in the level of fluoride in the water supply of at least one of the study areas, within three years of the baseline survey.

Outcomes:

- Any measure of dental decay

Study designs:

- Prospective studies comparing at least two populations, one receiving fluoridated the other non-fluoridated water, with at least two points in time evaluated.

OBJECTIVE 2. IF FLUORIDATION IS SHOWN TO HAVE BENEFICIAL EFFECTS, WHAT IS THE EFFECT OVER AND ABOVE THAT OFFERED BY THE USE OF ALTERNATIVE INTERVENTIONS AND STRATEGIES?

Participants:

- Populations receiving fluoridated water (naturally or artificially) in addition to other interventions.
- Populations receiving non-fluoridated water in addition to other interventions.

Intervention:

- A change in the level of fluoride in the water supply of at least one of the study areas, within three years of the baseline survey.

Outcomes:

- Any measure of dental decay.

Study designs:

- Prospective studies comparing at least two populations, to investigate the differences in levels of tooth decay between the populations in the presence of other sources of fluoride, e.g. fluoridated toothpaste. Where specific information on the use of other sources of fluoride is not supplied, populations in studies conducted after 1975 in industrialised countries were assumed to have been exposed to fluoridated toothpaste.

OBJECTIVE 3. DOES FLUORIDATION RESULT IN A REDUCTION OF CARIES ACROSS SOCIAL GROUPS AND BETWEEN GEOGRAPHICAL LOCATIONS?

Participants:

- Populations from different social groups and geographic locations receiving fluoridated water (naturally or artificially).
- Populations from different social groups and geographic locations receiving non-fluoridated water.

Intervention:

- Fluoride at any concentration present in drinking water, either controlled or naturally occurring

Outcomes:

- Any measure of dental decay.

Study designs:

- Any study design comparing two populations, one receiving fluoridated the other non-fluoridated water, across different social groups and geographic locations.

OBJECTIVE 4. DOES FLUORIDATION HAVE NEGATIVE EFFECTS?

Participants:

- Populations receiving fluoridated water (either naturally or artificially).
- Populations receiving non-fluoridated water .

Intervention:

- Fluoride at any concentration present in the water supply, either naturally occurring or artificially added.

Outcomes:

- Dental fluorosis, skeletal fluorosis, hip fractures, cancer, congenital malformations, mortality and any other possible negative effects reported in the literature.

Study designs:

- Any study design comparing the incidence of any possible adverse effect between two populations, one with fluoridated water and the other with non-fluoridated water.

OBJECTIVE 5. ARE THERE DIFFERENTIAL EFFECTS OF NATURAL AND ARTIFICIAL FLUORIDATION ?

Participants:

- Populations receiving artificially fluoridated water.
- Populations receiving naturally fluoridated water.

- Populations receiving non-fluoridated water.

Intervention:

- Fluoride at any concentration from a naturally or an artificially fluoridated water source.

Outcomes:

- Possible positive effects: Any measure of dental decay.
- Possible negative effects: Dental fluorosis, skeletal fluorosis, hip fractures, cancer, congenital malformations, mortality and any other possible negative effects reported in the literature.

Study designs:

- Any study design comparing populations exposed to different water fluoride concentrations, results obtained from areas using artificially and naturally fluoridated water supplies were compared to investigate any differences in effect.

Studies meeting the above objective specific criteria for inclusion were also assigned a level of evidence, as described above.

2.3 Assessment of papers for inclusion

2.3.1 Relevance assessment

Three reviewers independently assessed each title and abstract located through the searches for relevance to the review. Decisions about the inclusion of studies were made according to the following pre-determined criteria:

- Relates directly to fluoride in drinking water supplies.
- Is a primary study (not a review of studies).
- Research involves humans.
- Involves two groups with different fluoride concentrations in water supply.
- For caries studies: evaluates two points in time, one of which is less than three years since the change of water fluoridation status in one of the two groups.

Full articles of titles and abstracts found to be relevant to the review were obtained for full assessment of inclusion criteria.

2.3.2 Assessment of papers for inclusion criteria

Three reviewers independently assessed each paper for the pre-determined inclusion criteria, as stated above. Inclusion criteria were assessed for each of the objectives separately. Disagreements were resolved through consensus.

2.4 Data extraction

Extraction of data from individual included studies was independently performed by two reviewers, and checked by a third reviewer. Disagreements were resolved through consensus. Papers in languages other than English were assessed for inclusion criteria and data extracted using appropriate translators. Languages translated were Bulgarian, Chinese, Czech, Dutch, French, German, Greek, Hungarian, Italian, Portuguese, Russian and Spanish. Data were extracted into an MS Access database (Microsoft Corporation 1989-96). Tables showing baseline information and results were produced for each study and are presented in Appendix C.

2.5 Assessment of study validity

Study validity was formally assessed using validity checklists based on the checklist in NHS Centre for Reviews and Dissemination Report Number 4 (NHS CRD, 1996). The checklist was modified to address issues of water fluoridation. Separate checklists were devised for studies using a case-control design and all other study designs combined. These checklists are presented in Appendix D. Each study was assigned a ‘level of evidence’ using the definitions given above, and a validity score, based on the number of checks achieved on the checklist. The maximum score was 8 for all study designs except case control studies which had a total of 9 possible points. Study validity was assessed independently by two reviewers, with disagreements resolved through consensus.

The level of evidence (A, B, or C) is generic, and was used to classify studies for inclusion criteria based on overall quality and chance for bias. The validity assessment checklist is more specific to water fluoridation studies. Therefore, the validity checklist assessment is stricter.

2.6 Data analysis

Where the data were in a suitable format, measures of effect (with their 95% confidence intervals) for the major outcomes identified were shown on forest plots. This allowed a visual evaluation of the overall data set. The range of measures of effect for each outcome is also presented in the text.

Differences among studies may explain why individual studies report differing estimates of effect. These differences may relate to study design, geographic location, age of participants, type and duration of intervention, and methods of outcome assessment. Such differences between studies are known as heterogeneity, which may or may not be important. Some heterogeneity can be expected to occur by chance. A distinction is sometimes made between statistical heterogeneity (differences in the reported effects), methodological heterogeneity (differences in study design) and clinical heterogeneity (differences between studies in key characteristics of the participants, interventions or outcome measures). Statistical tests for heterogeneity are used to assess whether the observed variability in study results (measures of effect) is greater than that expected to occur by chance. If there is statistically significant heterogeneity between the estimates derived from different studies, this may result in a decision not to combine the studies in a meta-analysis. Statistical heterogeneity can exist even when all the studies included show an effect in the same direction (e.g. a protective effect), but there is variation in the estimate of the magnitude of the effect. Heterogeneity was investigated by visual examination of the forest plots and statistically using the Q-statistic. Even if the assessment of heterogeneity is not statistically significant there may be important heterogeneity.

Where no evidence of statistically significant heterogeneity was found, a meta-analysis was conducted to produce a pooled estimate of the measure of effect. The DerSimonian and Laird random effects model, which assumes that the study specific measures of effect come from a random distribution of measures of effect with a fixed mean and variance, was used to combine studies. It is a more conservative analysis, resulting in broader confidence intervals, used because some degree of underlying heterogeneity among the studies was assumed.

Tables indicating the general effect of fluoridation found in each study were created for each item, and, where possible, the point estimate and a measure of statistical significance (using the 95% confidence interval or p-value) of the finding was also included. Validity scores were included in these tables to allow assessment of the relationship between study quality and strengths of the association with fluoridation. Statistical analysis was carried out using StatsDirect (CamCode, England), Stata (Stata Corporation, USA), SAS (SAS institute Inc., USA) and Access (Microsoft Corporation, USA).

A table was not made for dental fluorosis, as the method of analysis used for this outcome differed from that used for other outcomes. The analysis used for fluorosis compared each fluoridated study area to each non-fluoridated study area, using a regression analysis, rather than comparing the differences found within each study to the differences found within other studies.

Where possible, meta-regression was used to investigate and explain sources of heterogeneity among studies. Meta-regression is an exploratory statistical analytical technique, which investigates the importance and nature of relationships between study results and study characteristics, and can be used to explore sources of heterogeneity. This is a modelling exercise that estimates the amount by which each identified 'predictor variable' (e.g. age) reduces the remaining heterogeneity. Dental caries and bone fracture results were analysed using meta-regression in order to assess the impact of potential sources of heterogeneity and estimate the underlying effect of water fluoridation. Meta-regression was carried out using Stata v. 6.0 (Stata Corporation, USA). The heterogeneity among fluorosis studies was explored by including variables that may account for the observed heterogeneity in the regression model.

Publication bias is defined as the failure to publish research on the basis of the nature and directional significance of the results. Because of this, systematic reviews that fail to include unpublished studies may overestimate the true effect of an intervention. The data provided by the studies included in this review were not in a suitable format to allow investigation of publication bias using standard procedures (e.g. Funnel plots), and so a narrative approach was used to discuss publication bias.

3. GENERAL RESULTS

3.1 General results

The search identified over 3200 papers, of which 734 met relevance criteria. Upon closer inspection, 254 of these met full inclusion criteria for one or more of the objectives; these 254 papers relate to 214 studies (some papers refer to the same study). Among these there were 26 studies relevant to Objective 1, the effect of water fluoridation on dental caries; 9 of these also met inclusion criteria for Objective 2. For Objective 3, 13 studies were included. For Objective 4, a total of 176 studies were included. There were 88 studies on dental fluorosis, 29 on bone fractures, 26 on cancer, and 33 studying other possible adverse effects. These included studies came from 30 countries, were published in 14 languages and ranged in publication dates from 1939 to 2000. No randomised controlled trials of the effects of water fluoridation were found. The study designs used included 45 'before and after' studies, 102 cross-sectional studies, 47 ecological studies, 13 cohort (prospective or retrospective) studies and seven case-control studies. Several studies were reported in multiple papers over a number of years. For example, the original studies from Michigan were published in six papers, between 1942 and 1962.

3.2 Validity assessment

None of the included studies were of evidence level A. The reason for this among the studies evaluating dental caries was that none addressed three or more confounding factors. For Objectives 1 and 2, all studies that met inclusion criteria were evidence level B. All but three of the studies assessing Objective 3, were evidence level C, the others were evidence level B. Among the studies of possible adverse effects of water fluoridation, Objective 4, the majority were found to be level C evidence because they lacked a prospective, longitudinal design. Studies used to compare the effects of natural versus artificial water fluoridation, Objective 5, were evidence level B for possible positive effects and mainly level C for possible negative effects. The validity checklist scores and level of evidence are presented in D.

3.3 Extracted data

Data extracted from all of the included studies are presented in tables in Appendix C. Each outcome is presented in two separate tables, the first listing baseline data about the groups being studied, such as location and year of study, gender, and the methods used to assess outcome. The second table presents the results of each study by each outcome.

3.4 Protocol changes

Changes to the original protocol were minimal. The wording of the objective specific inclusion criteria was altered to clarify the intent of the criteria. The range of analyses undertaken was broader than had been described in the protocol. Due to extremely limited evidence, the inclusion criteria for Objective 3 were expanded to include studies of level C evidence, and limited to studies from the UK. These changes were made with the consultation of and agreement from the advisory panel. Full details of changes are included in Appendix M.

4. OBJECTIVE 1

What are the effects of fluoridation of drinking water supplies on the incidence of caries?

A total of 26 studies of the effect of water fluoridation on dental caries were found, reported in 73 articles published between 1951 and 2000. Five unpublished studies were located (Hobbs 1994, Wragg 1992, Gray 1999, Holdcroft 1999 and Gray, 2000). The before-after study design was used in all but three of the included studies. The three exceptions were two prospective cohort studies (Hardwick 1982, Maupomé 2000) of caries in children and one retrospective cohort study (Pot 1974) of adults with false teeth. An example of the before-after design is a study in which two groups of 12-year olds from two similar populations were examined for prevalence of caries prior to initiating water fluoridation in one of the groups. Five years after starting water fluoridation, 12 year olds were examined in the two areas (one fluoridated, the other not). The rates of caries in the first groups were then compared with the rates in the second groups. It is important to note that the children are different in the before and after periods. All before-after studies identified by the search met the inclusion criteria. Three of the studies met inclusion criteria but were not included in the main analysis and are discussed in section 4.3 (Klein 1946, Holdcroft 1999 and Gray 2000). The Hardwick cohort study examined two groups of British children at age 12 prior to the initiation of fluoridation in the water supply of one group, and followed these same children with annual examinations for four years.

Seven studies assessed the effect of discontinuing water fluoridation, including seven before-after analyses and one cohort study (Attwood 1988, Hobbs 1994, Kalsbeek 1993, Kunzel 1997, Maupomé 2000, Seppa 1998 and Wragg 1992). The Maupomé cohort study examined two groups of 8 and 14 year-old children within 14 to 19 months after fluoridation was stopped in one area and continued in the other. These same children were then re-examined three years later. This study also included a second group of children 8 and 14 years old at the follow-up examination, and so is both a before-after and cohort design. Only one of the 26 studies included examined adults (Pot 1974).

The studies assessing efficacy of water fluoridation all achieved evidence level B, and an average checklist score of 5 out of 8 (range 3.5 to 6.8). The checklist items most commonly missed by these studies were blinding of the examiners assessing outcomes to the children's exposure status, reliable measurement (or adequate reporting) of the fluoride concentration, and adequate investigation of confounding factors. None attempted to control for confounders using multivariate analysis (a technique commonly used since the early 1980s). The only method used to address confounding was by presenting data stratified by age or gender. Many additional studies were excluded because they failed to include a baseline examination prior to starting or stopping water fluoridation.

The measure of effect measure used in the main analysis was the difference of the *change* in caries from the baseline to the final examination in the fluoridated compared with the control area (Appendix E). For example, the change in DMFT in the fluoridated area (final survey minus baseline survey) minus the change in DMFT in the control (non-fluoridated) area (final survey minus baseline survey) is the *difference* in the change in DMFT for that study. The two main outcomes investigated by studies estimating the effect of fluoridation on caries were DMFT (and dmft) score and the proportion of caries-free children (in both primary and secondary dentition).

Tables 4.1 - 4.5 show the 26 studies that have been included in assessing objective 1. In these tables, the mean difference of the change in caries measurement between the fluoride and control areas is shown. If the reduction in dental caries between pre- and post-fluoridation periods was greater in the fluoridated group than in the non-fluoridated group the mean difference will be greater than zero. Thus, a mean difference greater than zero indicates a benefit of water fluoridation and a mean difference less than zero indicates no benefit of water fluoridation. If the 95% confidence intervals include zero the difference is not statistically significant at the 5% level.

4.1 Studies in which fluoridation was initiated

Figure 4.1 shows the mean difference of the change in the proportion (%) of caries-free children in the exposed (fluoride) group compared with the control group (low fluoride), for all ages extracted (colour coded by age), for studies in which fluoridation was initiated after the baseline survey.

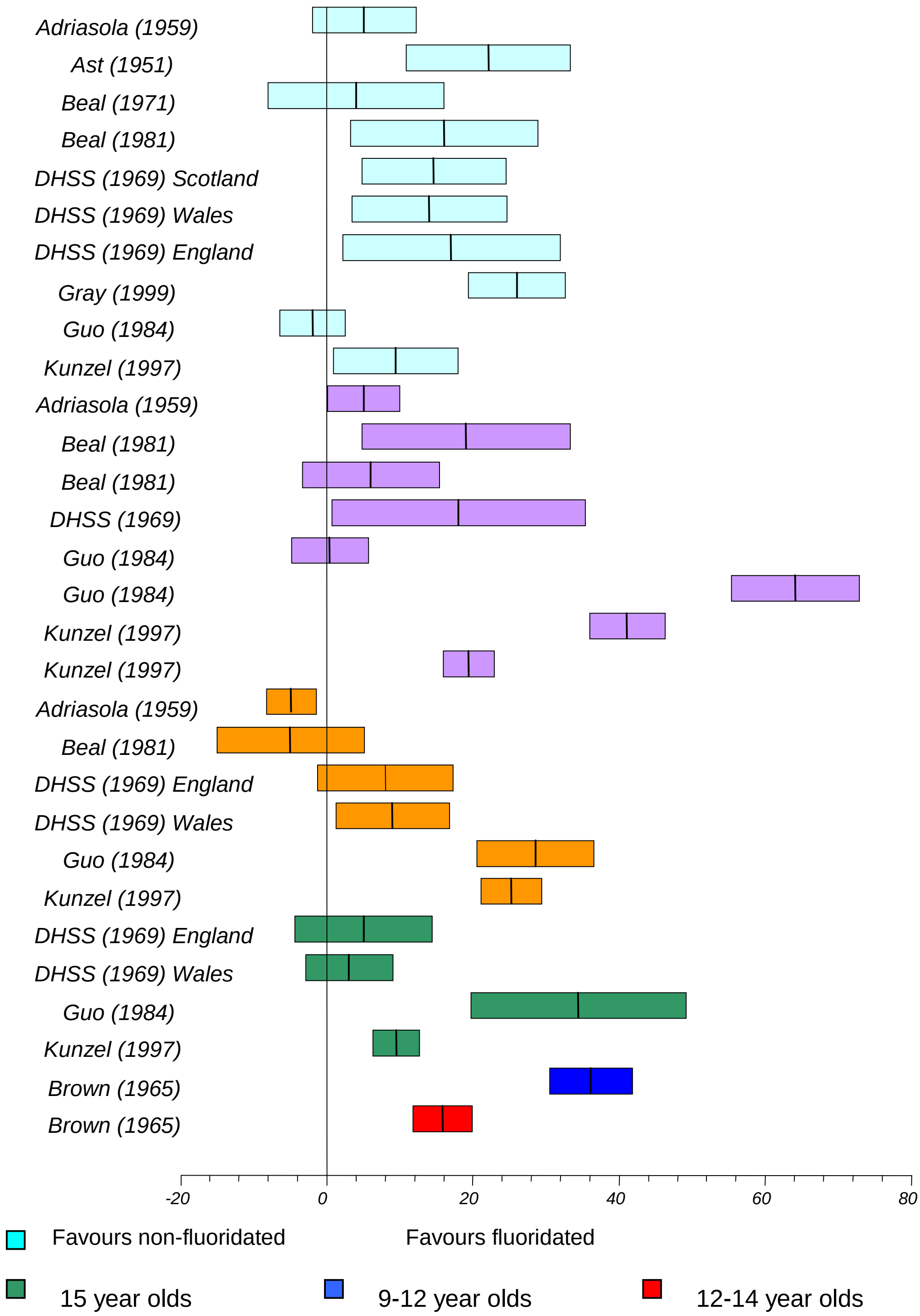

Figure 4.1: Increase in proportion (%) of caries-free children in fluoridated compared to non-fluoridated areas (mean difference and 95% CI)

The vertical line, at 0, is the 'no effect' line for measures of difference. Studies are indicated with a rectangle showing the 95% confidence intervals around the mean. The 95% confidence interval is the interval within which 95% of values of estimates derived from identified studies will fall. The rectangles are colour coded by age. If the rectangle crosses the 'no effect' line the difference is not statistically significant. If the rectangle is entirely to the right of the line the difference is statistically significant and fluoridation is associated with an increase in the proportion of children who are caries-free. If the rectangle is entirely to the left of the line the difference is statistically significant and fluoridation is associated with a decrease in the proportion of children who are caries-free.

The range of the mean difference in the proportion (%) of caries-free children is -5.0 to 64%, with a median of 14.6% (interquartile range 5.05, 22.1%). There was a statistically significant change, with a greater proportion of caries-free children in the fluoridated area, in 19 analyses. One analysis found a statistically significant greater decrease in the proportion of caries-free children exposed to fluoridated water compared with those exposed to non-fluoridated water. The remaining 10 analyses were unable to detect a statistically significant difference. It is estimated that a median of six people need to receive fluoridated water for one extra person to be caries-free (interquartile range of study NNTs 4, 9).

Figure 4.2 shows the mean difference of the change in dmft /DMFT in the exposed (fluoride) compared with the control group (low fluoride), separately by age (colour coded) for the four studies reporting dmft/DMFT, with 95% CIs.

Fifteen studies found a statistically significantly greater mean change in dmft/DMFT scores in the fluoridated areas than the non-fluoridated areas. The range of mean change in dmft/DMFT score was from 0.5 to 4.4, median 2.25 teeth (interquartile range 1.28, 3.63 teeth).

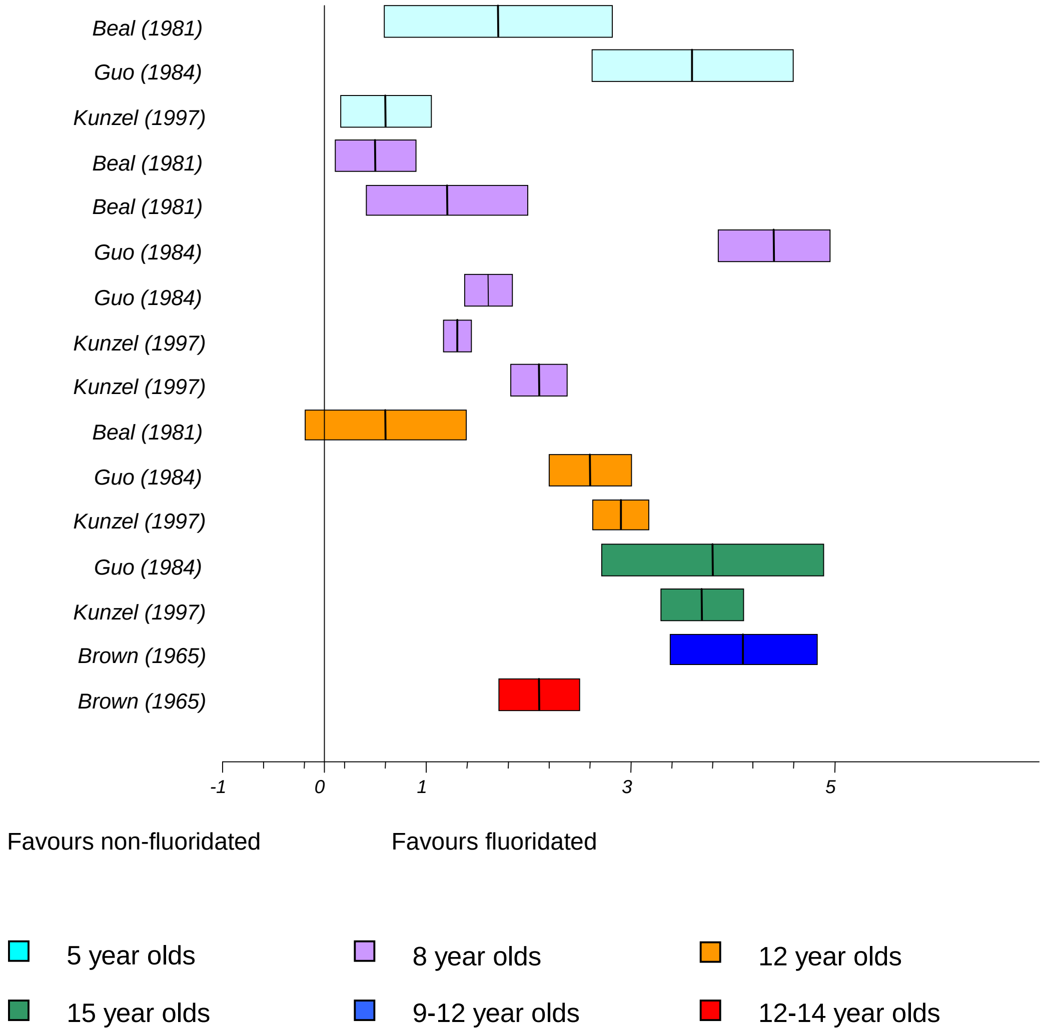

Figure 4.2: Change in dmft/DMFT Score (mean difference and 95% CI)

The Hardwick cohort study was plotted separately (figure 4.3) because the outcome measurements (increment in DMFT and DMFS) were too dissimilar to the others. In this study the effect of water fluoridation was assessed in the same children over a three-year period. This study showed a statistically significant mean difference in the increment in DMFT/DMFS score, with children in the fluoridated area having fewer *new* decayed, missing or filled teeth (or surfaces) after the three-year period. The examiners in this study were blind to the fluoridation status of the children.

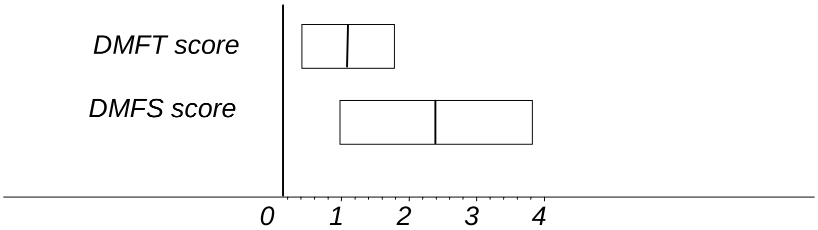

Figure 4.3 DMFT/DMFS increment over four years (mean difference and 95% CI)

Table 4.1 Mean difference of the change in the proportion of (%) caries-free children between the fluoride and control areas

Author (Year)	*Age*	Teeth Type	**Mean Difference** (95% CI)	Validity Score
Kunzel (1997)	5	Primary	**9.4** (0.9, 17.9)	**5.8**
	8	Permanent	**41.1** (36.0, 46.2)	
	8	Primary	**19.4** (15.9, 22.9)	
	12	Permanent	**25.2** (21.1, 29.3)	
	15	Permanent	**9.5** (6.3, 12.7)	
Beal (1981)	5	Primary	**16.0** (3.2, 28.8)	**5.5**
	8	Permanent	**19.0** (4.8, 33.2)	
	8	Primary	**6.0** (-3.4, 15.4)	
	12	Permanent	**-5.0** (-15.0, 5.0)	
DHSS (1969)	5	Primary	**17.0** (2.1, 31.9)	**5.5**
England	8	Not stated	**18.0** (0.7, 35.3)	
	12	Not stated	**8.0** (-1.2, 17.2)	
	14	Permanent	**5.0** (-4.4, 14.4)	
Wales	5	Primary	**14.0** (3.5, 24.5)	
	12	Not stated	**9.0** (1.2, 16.8)	
	14	Permanent	**3.0** (-2.9, 8.9)	
Scotland	5	Primary	**14.6** (4.79, 24.4)	
Adriasola (1959)	5	Primary	**5.1** (-1.9, 12.1)	**5.2**
	8	Not stated	**5.0** (0.1, 9.9)	
	12	Not stated	**-4.9** (-8.3, -1.5)	
Guo (1984)	5	Primary	**-2.0** (-6.4, 2.4)	**4.8**
	8	Permanent	**64.1** (55.4, 72.8)	
	8	Primary	**0.4** (-4.8, 5.6)	
	12	Permanent	**28.5** (20.5, 36.5)	
	15	Permanent	**34.4** (19.7, 49.1)	
Beal (1971)	5	Not stated	**4**(-8.0, 16.0)	**4.8**
Ast (1951)	5	Primary	**22.1** (10.9, 33.3)	**4.5**
Brown (1965)	12-14	Permanent	**15.8** (11.8, 19.8)	**4.5**
	9-11		**36.1** (30.5, 41.7)	
Gray (1999)	5	Primary	**26.0** (19.4, 32.6)	**3.5**

The associations that were found in the studies in which fluoridation was initiated are presented in Tables 4.1 and 4.2. Table 4.3 shows the results of studies using outcome measures other than the proportion of caries-free children or dmft/DMFT score. Some studies either did not provide data on the variance of the estimate of effect or the number of individuals studied. Further information was sought from the authors of these studies, however, only one author was contacted successfully.

Studies without variance data were not included in the plots or in the meta-regression. The reason for excluding data from further analysis is stated in the table.

Whilst in 27 of the 30 analyses the direction of association between water fluoridation and the change in the proportion of caries-free children was positive (fewer caries), in only 20 of these comparisons were the differences statistically significant. In three analyses the direction of association was negative (one in five-year-olds and two in 12 year-olds), but only one of these found a statistically significant effect (Table 4.1).

In all 31 analyses the direction of association of the dmft/DMFT scores with fluoridation status was positive. Standard error data were only available for 16 of these analyses, all but one of which showed a statically significant positive effect of fluoridation (Table 4.2).

Table 4.2 Mean difference of the change in dmft/DMFT between the fluoride and control areas

Author (Year)	Age	Teeth Type	Mean Difference *(95% CI)*	Included in Analysis	Reason not Included in Further Analysis	Validity Score
Kunzel (1997)	5 8 8 12 15	Primary Primary Permanent Permanent Permanent	**0.6** (0.2, 1.0) **2.1** (1.8, 2.4) **1.3** (1.2, 1.4) **2.9** (2.6, 3.2) **3.7** (3.3, 4.1)	Yes		**5.8**
Beal (1981)	5 8 8 12	Primary Permanent Primary Permanent	**1.7** (0.6, 2.8) **0.5** (0.1, 0.9) **1.2** (0.4, 2.0) **0.6** (-0.2, 1.4)	Yes		**5.5**
DHSS (1969) England	5 8 12 14	Primary Permanent Permanent Permanent	**1.6** **0.8** **1.0** **1.5**	No	No standard error data	**5.5**
Wales	5 12 14	Primary Permanent Permanent	**2.1** **2.5** **2.3**			
Loh (1996)	7-9 7-9	Permanent Permanent	**3.1** **2.1**	No	No standard error data	**5.1**
Guo (1984)	5 8 8 12 15	Primary Permanent Primary Permanent Permanent	**3.6** (2.6, 4.6) **1.6** (1.4, 1.8) **4.4** (3.9, 4.9) **2.6** (2.2, 3.0) **3.8** (2.7, 4.9)	Yes		**4.8**
Alvarez-Ubilia (1959)	5	Primary	**2.2**	No	No standard error data	**4.5**
Arnold (1956)	12 15 8	Permanent Permanent Permanent	**1.2** **3.1** **1.2**	No	No standard error data	**4.5**
Blayney (1960)	12 8	Permanent Permanent	**3.4** **1.8**	No	No standard error data	**4.5**
Brown (1965)	12-14 9-11	Permanent Permanent	**4.1** (3.4, 4.8) **2.1** (1.7, 2.5)	Yes		**4.5**

The study with the highest validity score (Hardwick, 1982) showed a statistically significant difference in the increment in both DMFS and DMFT scores, with a lower increment in the fluoridated area compared with the control area. One study (Backer-Dirks, 1961) considered the average number of all dentinal lesions and the average number of approximal dental lesions. This study found the direction of association of fluoridation with caries to be positive (fewer caries) but no measure of the statistical significance of this effect was provided. Two studies (Beal, 1971 and Arnold, 1956) looked at deft score. Whilst both these studies found the direction of association to be positive, only one of these studies (Beal, 1971) provided standard error data. This study showed a statistically significant positive effect of fluoridation. One study (Ast, 1951) compared the number of erupted teeth per child before and after fluoridation was initiated and found the direction of association to be positive with fluoridation (more erupted teeth per child) in 12 year-olds but negative in 8 year-olds. No measure of the statistical significance of this association was provided, however, and the difference was so small that is unlikely that there was a statistically significant difference in the number of erupted teeth in the fluoridated compared with the control area. This same study also looked at the DMFT rate per 100 erupted teeth and found the direction of association to be positive (greater decrease in the DMFT rate in the fluoridated area compared with the control area) with water fluoridation. However no measure of the significance of this association was provided. One study (Pot, 1974) found the proportion of adults with false teeth to be statistically significantly greater in the control (low-fluoride) area compared with the fluoridated area.

Table 4.3 Mean difference of the change in other caries measurements between the fluoride and control areas

Author (Year)	Age	Mean Difference *(95% CI)*	Outcome	Validity Score
Hardwick (1982)	12 12	**2.5** (1.0, 3.9) **1.1** (0.4, 1.8)	Increment in DMFS score Increment in DMFT score	**6.8**
Backer-Dirks (1961)	11-15 11-15	**2.7** **1.4**	Average number of all approximal lesions Average number of approximal dentinal lesions	**5.0**
Beal (1971)	5	**2.5** (1.3-3.7)	deft score	**4.8**
Arnold (1956)	5 8	**1.6** **0.9**	deft score	**4.5**
Ast (1951)	12 8 12 8	**0.1** **-0.3** **10.5** **7.1**	Number of erupted permanent teeth per child DMFT rate per 100 erupted permanent teeth	**4.5**
Pot (1974)	5-55	**11.2** (3.8, 18.6)	% with false teeth	**4.0**

4.2 Studies in which fluoridation was discontinued

Figure 4.4 shows the mean difference of the change in the dmft/DMFT and DMFS score in children in the exposed (fluoride) group compared with the control group (low fluoride), in studies in which fluoridation was discontinued after the baseline survey.

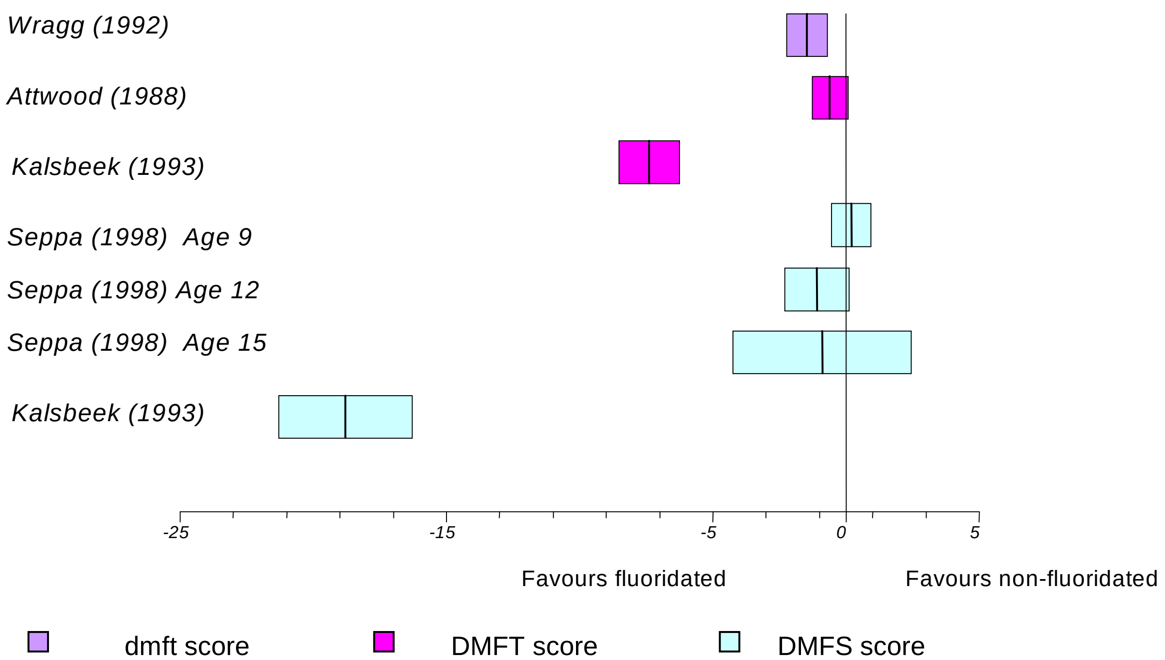

Figure 4.4: Stopping fluoridation: dmft/DMFT or DMFS score (mean difference and 95% CI)

The range of measures of effect in dmft/DMFT scores (Figure 4.4) is –7.4 to –0.6. Two of the three studies using dmft/DMFT show a statistically significant difference: when fluoridation was discontinued there was a greater increase in caries in the fluoridated compared with the control area suggesting that fluoridation had been beneficial. The range in measures of effect for DMFS score was –18.8 to 0.2, with all but one of the studies suggesting that stopping water fluoridation had led to a greater increase in caries in the previously fluoridated area than in the non-fluoridated area. Only one of the four analyses using DMFS found a statistically significant difference. The three analyses that did not find a statistically significant effect all came from the same study (Seppa, 1998), but relate to different age groups (ages 9, 12 and 15 shown in ascending order of age on the graph).

Table 4.4 shows the results of the studies that examined the effects of stopping water fluoridation. In this table a positive difference indicates that the difference between the fluoridated and non-fluoridated areas in the caries outcome became greater after the cessation of water fluoridation. A negative difference shows that the difference narrowed when fluoridation stopped.

Table 4.4 Mean difference in caries outcome measures in studies in which fluoridation was discontinued

Author (Year)	Age	Teeth Type	Mean Difference *(95% CI)*	Validity Score
Proportion of caries-free children				
Kunzel (1997)	8 12 15	Permanent	**8.6** **-5.3** **-2.5**	**5.8**
DHSS (1969)	5	Primary	**-2.7**	**5.5**
Wragg (1992)	5	Primary	**-21.6** (-37.1, -16.3)	**4.5**
Mean difference in dmft/DMFT				
Kunzel (1997)	12 15 8	Permanent Permanent Permanent	**0.1** **-0.4** **0.3**	**5.8**
Kalsbeek (1993)	15	Permanent	**-7.4** (-8.5, -6.3)	**5.5**
DHSS (1969)	5	Primary	**-16**	**5.5**
Attwood (1988)	10	Permanent	**-0.6** (-1.3, 0.1)	**4.8**
Hobbs (1994)	5	Primary	**-1.2**	**4.5**
Wragg (1992)	5	Primary	**-1.5** (-2.2, -0.7)	**4.5**
DMFS score				
Seppa (1998)	6 9 12 15	Not stated Permanent	**-0.1** **0.2** (-0.5, 0.9) **-1.1** (-2.3, 0.1) **-0.9** (-4.2, 2.4)	**5.8**
Kalsbeek (1993)	15	Permanent	**-18.8** (-21.3, -16.3)	**5.5**
Mean Difference in D1D2MFS* Scores				
Maupomé (2000)	8 14	Permanent	0.59 (0.41, 0.77) 1.39 (0.23, 2.55)	**6.0**
D1D2MFS* Incidence				
Maupomé (2000)	11 17	Permanent	0.13 (-0.07, 0.34) 0.47 (-0.02, 0.96)	**6.0**

*D1D2MFS is a modified DMFS score where D1 = an incipient lesion, D2 = a cavitated lesion

Of 22 analyses of stopping water fluoridation, 14 found the direction of association to be negative (that stopping water fluoridation led to an increase in caries in the previously fluoridated area compared to the never-fluoridated area). However only eight of these studies provided a measure of the significance of this association. Four of these analyses found that stopping water fluoridation had a statistically significant effect at the 5% level, while the other four did not. Eight analyses found the direction of association to be positive (that stopping fluoridation had not led to increases in caries in the previously fluoridated areas). Seven of these analyses (from Seppa 1998 and Maupomé 2000 of both before-after and cohort analyses), provided standard error data. Only the Maupomé before-after study found a statistically significant association, in both 8 and 14 year olds.

The Maupomé study also included a multiple regression on both the before-after and cohort data including age, sex, socio-economic status, site (still fluoridated or no longer fluoridated), use of snacks, swallowing of toothpaste, use of fluoride supplements and brushing/rinsing regime. For prevalence of D1D2MFS, higher age and lower socio-economic status were statistically significantly associated with caries prevalence. Higher scores were associated with the still-fluoridated site for the D1D2MFS score and D1 alone, but higher D2 alone scores were associated with the fluoridation ended site. For the cohort data, the regression analysis showed again that higher age and lower socio-economic status were associated with higher D1D2MFS scores. However, the association between score and site (still fluoridated or fluoridation ended) were less clear.

4.3 Studies which met inclusion criteria but were not included in the main analysis

Table 4.5 is a summary of the studies that met our inclusion criteria, but contained data in forms that could not be used in the pre-defined analysis. The data used in the reports by Holdcroft and Gray were derived from the British Association for the Study of Community Dentistry (BASCD) survey data. Each year the BASCD conducts an epidemiological survey of dental health in the UK. Every second year, 5-year-old children are examined in most regions of the UK (either a random sample or the whole population of a given health authority). These surveys are co-ordinated and published by the University of Dundee.

Table 4.5 Included studies from which relevant data could not be derived

Author (Year)	Outcome	Reason	Author's Conclusions
Klein (1946)	Caries	Different caries measurement at baseline and final surveys	Author states that the findings of this report support a beneficial role of fluoride in caries prevention
Holdcroft (1999)	dmft	Results presented for 14 areas, no pairing of exposed and control areas so could not make direct comparisons	The conclusion of this study was that significant improvements in dmft levels is possible in non-fluoridated districts. When measured against fluoridated districts, it implies that the effectiveness of fluoridation is at least exaggerated. Efforts to improve dental health outside of the influence of drinking fluoridated water will impact changes in dmft level.
Gray (2000)	dmft	Results presented for 10 areas, 6 areas fluoridated, no pairing of exposed and control areas so could not make direct comparisons	After 10 years of fluoridation dental decay was lower in the fluoridated than in the low fluoride areas.

4.4 Studies with more than two study areas

The majority of studies assessing caries compared one fluoridated area to one non-fluoridated area. However, there were five studies with more than two study areas, such as two fluoridated areas compared with one non-fluoridated area. In the DHSS Welsh studies (DHSS 1969), data from Holyhead were excluded from the analysis because although Holyhead usually received fluoridated water, occasionally the water supply was supplemented from a non-fluoridated source.

For two studies (Gray 1999, Wragg 1992) the data from the two areas with the same fluoride level in their water supplies were combined as no differences between the study areas were discussed. In the Beal (1971) study, two of the study areas were similar in social class structure (one fluoridated and one non-fluoridated area) while the other fluoridated area had a higher proportion of immigrants and was poorer on the basis of a number of indicators than the other two. Therefore, this area was dropped from the analysis and only the two similar areas were included. The comparison of the lower social class area with the higher social class area is considered under Objective 3.

The fifth study with more than two areas was the Canadian study of the Brantford-Sarnia-Stratford areas (Brown 1965), which included a non-fluoridated area, an artificially fluoridated area, and a naturally fluoridated area. The non-fluoridated and artificially fluoridated areas were used for the analysis of Objective 1, while the comparison of artificial and naturally fluoridated areas is considered under Objective 5.

4.5 Possible confounding factors

There are a number of potential confounding factors in assessing the development of caries within studies. Age, gender, social class, ethnicity, country, tooth type (primary or permanent), mean daily regional temperature, use of fluoride, total fluoride consumption, method of measurement (clinical exam, radiographs, or both), and training of examiners are all possible confounding factors. While most studies described the age of participants, data on other potential confounders were rarely available. Another possibly important confounding factor is the *number of erupted teeth per child*. It has been suggested that fluoridation may delay the eruption of teeth and thus caries incidence could be delayed as teeth would be exposed to decay for a shorter period of time. Only one study compared the number of erupted teeth per child. The difference was very small and in opposite directions in the two age groups examined, however no measure of the statistical significance of these differences was provided. Only one of the studies attempted to control for confounding factors using multivariate analysis (Maupomé 2000).

4.6 Meta-regression

A meta-regression analysis was undertaken to investigate possible sources of heterogeneity between studies. Variables that may account for the differences in measures of effect seen among different studies (or in this case each different measure of effect included in the analysis) were included in the regression model. Variables included in the analysis relate to study design and patient characteristics. The analysis aims to investigate why there is a difference in the measure of effect calculated from each study rather than why caries prevalence differs between study areas within studies.

The outcome measure used for this analysis is different from that used in previous analyses. The outcome measure used is taken from only the final survey data and corresponds to the mean difference (MD) for the dmft/DMFT data and the risk difference (RD) for the proportion of caries free children data. The reason for using only data from the final survey was to allow investigation of the effect of baseline caries levels by including this as a variable in the meta-regression. If the mean difference of the change in caries incidence was used as the outcome measure (as it has for the earlier analyses) this may lead to a spurious association being found, due to the correlation between the outcome variable and the baseline caries variable.

A paired t-test was carried out to investigate whether there were any statistically significant differences between caries prevalence (as measured by the proportion of caries-free children or dmft/DMFT) in the two study areas at baseline for each study (Appendix J). No statistically significant differences were found ($p= 0.97$ for proportion caries-free children and $p=0.77$ for dmft/DMFT), and so the final outcome measures could be taken as measures of the effect of fluoridation on caries incidence. This also permitted the calculation of the mean proportion of caries free children or dmft/DMFT at baseline for each study, this variable was included in the regression analysis as an estimate of caries experience at baseline for each study comparison.

The analysis was carried out separately for the two main caries outcome measurements: the proportion (%) of caries-free children and dmft/DMFT. Data on possible sources of heterogeneity were extracted from the studies where possible. If not described in the paper, data on altitude and mean daily temperature were obtained from published sources.

The studies included in this analysis contribute more than one estimate to the meta-regression, although different children contribute to the different estimates within studies. It has been assumed in this analysis that these subgroups of people are independent, and hence each estimate has been treated as though it came from a separate study. For example, most of the studies report results separately for children of more than a specific age, so the results for each age group were included separately in the analysis. The potential limitations of including this type of data are discussed in section 12.6.

Continuous measures were centred on the mean (the mean value of each variable was subtracted from each of the individual measures), before including them in the regression model. Centering continuous variables in this way results in the constant (or intercept) of the regression model pertaining to the pooled estimate of the measure of effect when the explanatory variable takes its mean value.

A univariate analysis was undertaken in which each of the variables was included individually in the regression model with the measure of effect. The random effects meta-regression models (mixed models) were implemented. to combine studies. Although age is related to tooth type (primary or permanent) both were included in the univariate analyses because the 8 year-old age group could have primary and/or permanent teeth. However, neither of the multivariate models included both terms.

A measure of the between study variance (heterogeneity) remaining after the variables included in the model had been accounted for was calculated using restrictive maximum likelihood estimation. Variables which showed a statistically significant association with the measure of effect (MD or RD) at the 15% statistical significance level ($p<0.15$) in the univariate analysis were included in the multivariate analysis. This significance level was chosen to conservatively identify variables that could potentially be important in the multivariate model. The multivariate analysis was carried out using a step-down analysis in which each variable was included in the initial model. Variables were dropped one by one, with the variable that showed the least evidence of a statistically significant association dropped first, until only variables which showed a statistically significant association at the 5% level were included in the analysis. The analysis was repeated using a step-up analysis to confirm the results of the step-down analysis. As a further exploratory analysis study validity was forced into the regression model as the effect of study validity was considered to be very important in these studies of variable quality. However, study validity was not found to be statistically significantly associated with the dependent variable in the analysis of dmft/DMFT score. The results of this analysis are presented in Appendix L.

4.6.1 Proportion (%) of caries-free children

A total of 31 RD estimates from 9 studies were included in the analysis. Several of these RD estimates came from the same study as each study provided estimates for more than one age group.

4.6.1.1 UNIVARIATE ANALYSIS

The results of the univariate analysis are shown in Table 4.6.

Table 4.6 Results of the univariate meta-regression analysis for the proportion of caries-free children

Variable	Category or mean	Constant (95%CI)	p-value of constant	Co-efficient (95%CI)	p-value of co-efficient	Between study variance
No variables (pooled estimate)		15.4 (10.8, 20.1)	<0.001			163.0
Baseline %caries-free subject *	19.4	15.5 (11.7, 19.3)	<0.001	0.4 (0.2, 0.6)	<0.001	105
Tooth type (n=29)*	Not stated	8.4 (0.4, 16.5)	0.039			136
	Permanent			13.4 (6.1, 23.6)	0.011	
	Primary			3.6 (-7.9, 15.2)	0.538	
Setting*	Taiwan	20.5 (9.6, 31.3)	<0.001			145
	Europe			-5.19 (-17.5, 7.1)	0.407	
	N. America			1.17 (-15.2, 17.6)	0.889	
	Chile			-20.3 (-37.9, -2.6)	0.025	
Study duration*	9.0	15.4 (10.9, 19.8)	<0.001	1.30 (0.0, 2.6)	0.049	147
Year of final survey	1969	15.4 (10.8, 20.1)	<0.001	0.24 (-0.2, 0.7)	0.279	162
Number of years since change in fluoridation status	0.5	13.3 (5.9, 20.7)	<0.001	-2.1 (-7.6, 3.5)	0.462	165
Age (years)	8.8	15.5 (10.7, 20.2)	<0.001	-0.23 (-1.6, 1.1)	0.739	167
Validity score*	5.2	15.5 (10.7, 20.2)	<0.001	-1.17 (-10.0, 7.7)	0.796	168
Average temperature (^{o}C)	11.7	15.4 (10.7, 20.2)	<0.001	0.11 (-0.7, 1.0)	0.795	168

*Included in multivariate analysis

The p-value shows whether the co-efficient is statistically significantly different from 0. If it is not statistically significantly different from 0 then this variable is not statistically significantly associated with the dependent variable (i.e. RD of proportion of caries-free children). The between study variance shows the estimate of the heterogeneity which is left between the estimates of the MD after that variable has been controlled for.

The model in which no variables (other than the risk difference) were included shows the pooled estimate of the risk difference of the change in the proportion of caries-free children to be 15.5% (95% CI: 10.8, 20.1). This is the same as the measure that would be produced by a standard meta-analysis. However, the measure of between study variance (heterogeneity) is large and highly statistically significant (p<0.001) and so this value should be interpreted with *extreme caution*.

At the 15% statistical significance level the following variables showed a statistically significant association with the risk difference: tooth type, study duration, setting, and baseline proportion of caries-free children. The risk difference increased with increasing proportion of caries-free children at baseline and study duration, and was greater in permanent teeth than in primary teeth and than in studies in which tooth type was not stated. The risk difference also varied according to setting and was greater in Taiwan and the North America and lower in Europe and Chile. Age, number of years since change in fluoridation status, average temperature, study validity and year of final survey did not show an association with the risk difference of caries incidence. Study validity was forced into the regression model for the reasons discussed above.

4.6.1.2 MULTIVARIATE ANALYSIS

The multivariate model shows the effect of each variable controlled for the possible effects of the other variables included in the model. The results of the multivariate analysis are shown in Table 4.7. All the variables were centered in the same way as in the univariate analysis.

Table 4.7 Results of the multivariate meta-regression analysis for the proportion of caries-free children

Variable	Category (mean)	Co-efficient (SE)	p-value	Between study Variance
Constant		14.3 (6.7, 21.9)	<0.001	53.1
Baseline %caries-free children	19.4	0.61 (0.43, 0.80)	<0.001	
Setting	Taiwan			
	Europe	-1.85 (-10.9, 7.2)	0.688	
	N. America	22.90 (10.7, 35.1)	<0.001	
	Chile	-4.71 (-17.1, 7.7)	0.456	
Validity score	5.2	16.78 (8.9, 24.7)	<0.001	

The proportion of caries-free children at baseline, setting and validity score show a statistically significant association at the 5% level with the risk difference of the proportion of caries-free children between fluoridated and control areas. These variables appear to account for a lot of the variation seen in the initial model where the measure of heterogeneity was 163. Including these variables in the regression model reduced the between study variance to 53. In this model the MD increases with increasing caries-free children at baseline, validity score and study duration, and is greatest in North America and Taiwan and is lowest in Europe and Chile. The model obtained using a step-up regression analysis was similar. The association of validity score with the risk difference is in the opposite direction in the univariate to that in the model presented above (negative association in the univariate, positive association in the multivariate). The reason for this is unclear but it is possible that this is related to the fact that setting, validity score and study duration will be the same for each analysis from the same study and thus some degree of colinearity is likely to exist between these three variables. It should also be noted that the association was not significant in the univariate analysis suggesting that one or more of the other variables included in the multivariate analysis act to confound the relationship between study validity score and the risk difference.

4.6.2 dmft/DMFT

4.6.2.1 UNIVARIATE ANALYSIS

A total of 16 MD estimates from 4 studies were included in the analysis. The results of the univariate analysis are shown in Table 4.8.

Table 4.8 Results of the univariate meta-regression analysis for dmft/DMFT score

Variable	Category or mean	Constant (95% CI)	p-value of constant	Co-efficient (95% CI)	p-value of co-efficient	Between study Variance
No variables (pooled estimate)		2.3 (1.8, 2.8)	<0.001			1.068
Baseline dmft/DMFT *	3.6	2.3 (1.9, 2.7)	<0.001	0.3 (0.1, 0.5)	0.006	0.713
Setting*	UK	1.3 (0.4, 2.2)	0.005			0.777
	Germany			0.9 (-0.3, 2.1)	0.135	
	N America			1.9 (0.4, 3.5)	0.014	
	Taiwan			1.5 (0.3, 2.8)	0.013	
Study duration (years)*	10.7	2.3 (1.9, 2.8)	<0.001	0.2 (0.03, 0.4)	0.018	0.815
Validity score*	5.3	2.3 (1.8, 2.8)	<0.001	-1.0 (-1.9, 0.0)	0.048	0.897
Age (years)*	9.5	2.3 (1.8, 2.8)	<0.001	0.1 (-0.01, 0.3)	0.062	0.903
Temperature (^{o}C)	13.3	2.3 (1.8, 2.8)	<0.001	0.0 (-0.03, 0.1)	0.229	1.04
Number of years since change in fluoridation status	-0.6	2.2 (1.3, 3.0)	<0.001	-0.1 (-0.6, 0.4)	0.707	1.13
Year of final survey	1975	2.3 (1.8, 2.9)	<0.001	0.0 (-0.1, 0.1)	0.906	1.14
Tooth type	Primary	2.3 (1.5, 3.2)	<0.001			1.14
	Permanent			0.0 (-1.1, 1.1)	0.938	

*Included in multivariate analysis

The model in which no variables (other than the MD) were included shows the pooled estimate of the MD in dmft/DMFT between the fluoridated and control areas to be 2.3 (95% CI: 1.8, 2.8). This is the same as the measure that would be produced by a standard meta-analysis. However, the measure of between study variance (heterogeneity) is large and highly statistically significant (p<0.001) and so this value should be interpreted with *extreme caution*.

At the 15% statistical significance level the following variables showed a statistically significant association with the MD: baseline dmft/DMFT, setting, study duration, validity score and age. The MD was highest in Taiwan and North America, followed by Germany and the UK. Study duration, age, and baseline dmft/DMFT score showed a positive association with the MD – as the value of these variables increased so did the MD. Validity score showed a negative association with MD with the lowest validity studies showing a greater MD.

4.6.2.2 MULTIVARIATE ANALYSIS

Table 4.9 Results of the multivariate meta-regression analysis for dmft/DMFT score

Variable	*Mean*	Co-efficient	p-value	Variance
Constant		2.61 (2.31, 2.91)		0.111
Baseline dmft/DMFT	3.6	0.37 (0.26, 0.48)	<0.001	
Age (years)	9.5	0.11 (0.04, 0.18)	0.001	
Study duration (years)	10.7	0.26 (0.18, 0.34)	<0.001	
Setting*	UK			
	Germany	-0.74 (-1.20, -0.29)	0.001	
	N. America	-0.57 (-1.27, 0.13)	0.112	
	Taiwan	Droppped	dropped	

Age, baseline dmft/DMFT, setting and study duration show a statistically significant association at the 5% level with the MD in the dmft/DMFT. These variables appear to account for a lot of the variation seen in the initial model where the measure of heterogeneity was 1.07. Including these variables in the regression model reduced the between study variance to 0.111. All of the variables except study setting showed a positive association with the MD – as each variable increases so does the MD. Setting shows that the MD was smaller in Germany and North America than in the UK. There was insufficient data for the effects of Taiwan to be investigated and this was dropped from the analysis. The analysis was repeated using a step-up analysis and produced similar results. Validity score was did not show a significant association with the MD in the multivariate model. The model in which study validity was included is presented in Appendix L. Forcing study validity into the model had very little effect on the co-efficients and standard errors of the other variables.

4.7 Numbers needed to treat

The number needed to treat (NNT) represents the number of children that need to receive the intervention for one person to benefit from the intervention. The NNT can be calculated by taking the inverse of the risk difference. This is the measure that was calculated for the meta-analysis of the proportion of caries free children above. In this case it represents the number of people exposed to fluoridation for one additional child to be caries-free. An NNT is valid only for the comparison it is based on, for example water fluoride levels < 0.7 ppm versus 0.7 to 1.2 ppm.

The risk difference was calculated for each study comparison – for some studies more than one risk difference was calculated if caries measurement was made in more than one age group. A meta-analysis was conducted to provide a pooled estimate of the mean risk difference between the exposed and control groups. This was carried out for all teeth types combined (permanent, primary and not stated) and separately for permanent and primary teeth. Heterogeneity was investigated and found to be statistically significant in all models (the Q statistic) and so the results of these analyses should be interpreted with caution.

Table 4.10 Meta analysis of risk difference in the proportion (%) of caries-free children

Tooth type	Age	Number of studies	Risk Difference % (95% CI)	Q-statistic – measure of heterogeneity	P-value for heterogeneity at the 5% level	NNT (95% CI)
All	All	31	15.5 (10.7, 20.2)	1421.0	<0.001	6 (5, 9)
Primary	All	15	11.4 (6.5, 16.3)	354.4	<0.001	9 (6, 15)
Permanent	All	16	19.1 (11.4, 26.7)	751.3	<0.001	5 (4, 9)
Primary	5	11	13.2 (6.8, 20.0)	137.5	<0.001	8 (5, 15)
Primary	8	4	7.2 (-3.6, 18.0)	211.3	<0.001	14 (6, ∞)
Permanent	8	4	35.6 (22.4, 48.8)	39.1	<0.001	3 (2, 5)
Permanent	12	6	13.1 (0.8, 25.5)	215	<0.001	8 (4, 125)
Permanent	14 -15	4	8.8 (0.7, 16.9)	36.8	<0.001	11 (6, 143)

The numbers needed to treat with 95% confidence intervals are given in the final column of Table 4.10. For all teeth combined 6 people need to receive fluoridated water for one extra person to be caries-free, with a 95% confidence interval of between 5 and 9 people. Due to the heterogeneity the median risk difference was calculated for all teeth combined, for primary teeth and for permanent teeth. This was translated into a number needed to treat. The median NNT for all teeth combined was 6, for primary teeth was also 6 and for permanent teeth was 5. These numbers are very similar to those obtained using the meta-analysis suggesting that these figures are a relatively accurate estimation based on the data from the studies included in this analysis.

To investigate whether including estimates for multiple ages from one study in the meta-regression as if they were independent was leading to bias in the result, NNTs were calculated separately for each tooth type and age group (Table 4.10). The NNT was greater in primary than in permanent teeth and within permanent teeth increased with age. This would be expected as the univariate meta-regression showed that age had a negative association with the risk difference (and hence a positive association with the NNT), although this relationship was not significant in the multivariate analysis. The estimates of the risk difference were positive for all age groups reported. The variation in RD and NNT suggests that although there may have been some bias introduced by including estimates for multiple ages from the same study as if they were independent, this does not alter the conclusion that the overall effect is positive.

4.8 Publication bias

Although it is possible to create a funnel plot from the studies including the proportion (%) of caries-free children this has not been done because some studies would contribute several points, this would make the funnel plot difficult to interpret. It would be possible to take only one point from each study but this would only give nine points that would also lead to problems with regard to interpreting the plot. It is thus difficult to estimate whether publication bias is having an effect. It has been argued that it is easier to get a study published that shows a beneficial effect of water fluoridation. However, considering the broad approach to searching for studies and the inclusion of unpublished studies in this report it is unlikely that any major studies on the association of dental caries with water fluoridation have been missed. Importantly, any missed study would have to be very large, and very different to those that were included to overturn the overall result.

4.9 Discussion

Objective 1 attempts to assess the effect of water fluoridation on the development of caries. A small number of studies meeting the pre-defined criteria were found. While many cross-sectional studies exist, relatively few studies were designed to assess the effects of water fluoridation over time. Studying populations exposed or not exposed to water fluoridation longitudinally allows baseline dental health to be taken into account and differences developing over time to be assessed. Studies that assess dental caries at one point in time using an ecological or cross-sectional study design only show the differences in caries prevalence at that particular point in time. In such studies it is not possible to tell whether the observed differences have always existed between these populations or whether they are the result of the differing levels of water fluoride content between the study areas.

When diagnosing caries it is usual to have very specific written criteria. However, these criteria vary from study to study. In particular, they have changed over time as treatment philosophies have also changed. This means that there is likely to be inter-study variation in the threshold at which caries is diagnosed. What is more important is whether the diagnostic criteria have remained the same within studies. As this systematic review has used the difference in change between DMFT/dmft the intra-study variation is likely to be of minimal importance.

For this objective, the quality of studies found was only moderate (level B). A large number of studies were excluded because they were cross-sectional studies and therefore did not meet the inclusion criteria of being evidence level B or above. All but one of the studies included were before-after studies; three included studies used a cohort design, two prospective and one retrospective. The most serious defect of these studies was the lack of appropriate analysis. Many studies did not present an analysis at all, while others only did simple analyses without attempting to control for potentially confounding factors. Although the size of the differences found might be affected by confounding factors, the differences estimated in this review were sufficiently large that it is unlikely that confounding factors would account for them entirely. While some of these studies were conducted in the 1940's and 50's, prior to the common use of such analyses, studies conducted much later also failed to use methods that were commonplace at the time of the study. As an example, no study used an analysis that would control for the frequency of sugar consumption or the number of erupted teeth per child. Another defect of many studies was the lack of any measure of variance for the estimates of decay presented. This was not so much of a problem for the studies, which presented the proportion of caries-free children, as all these studies contained sufficient data to calculate standard errors for the data provided. However, for the studies that presented dmft/DMFT scores this was more of a problem with only four of the eight studies providing any estimate of variance.

To have clear confidence in the ability to answer the question in this objective, the quality of the evidence would need to be higher. The failure of these studies to deal with potential confounding factors or to provide standard error data means that the ability to answer the objective is limited.

Tables 4.1 to 4.3 and Figures 4.1 and 4.2 suggest, through a simple qualitative method of analysis, using means, and confidence intervals where available, that water fluoridation does appear to reduce caries. Table 4.4 shows that when water fluoridation is stopped, in 12 out of 16 studies the direction of the association is that the caries burden increases more in the previously-fluoridated groups than in the never fluoridated groups. Only eight of these studies provided a measure of the significance of this association and of these, four showed a statistically significant positive effect. When fluoridation is discontinued caries prevalence appears to increase in the area that had been fluoridated compared with the control area. Interpreting from this data the degree to which water fluoridation works to reduce caries is more difficult.

The meta-analysis showed a statistically significant effect of water fluoridation in reducing dental caries as measured by both dmft/DMFT and the proportion of caries-free children. However, the results showed statistically significant evidence of heterogeneity and thus the pooled estimates should be interpreted with caution. The meta-regression carried out to investigate the heterogeneity between studies showed that, for both dmft/DMFT and the proportion of caries-free children, the baseline caries measurement and study duration both accounted for a significant proportion of this heterogeneity. For both these outcome measurements, increased duration of follow up was associated with a greater difference in the change in caries measurement from baseline to final examination in the fluoridated compared with the control group.

The baseline measure of dental caries also showed a positive association with the mean difference. This is what would be expected for dmft/DMFT: the greater the population prevalence of tooth decay at the baseline examination the greater the effect of water fluoridation in decreasing this decay in the fluoridated area. However, the situation is slightly more complex for the proportion of caries-free children. The results suggest that the greater the proportion of caries-free children at baseline (i.e. the less decay in the population) the greater the change in the mean difference. This is possibly related to the distribution of caries-free children within a population. A population with a high proportion of caries-free children will also probably have more children with few decayed teeth than a population with a small proportion of caries-free children, which is likely to have more children with more decayed teeth. Such a population would only require a small decrease in decay for a noticeable increase in the proportion of caries-free children.

The meta-regression of the proportion of caries-free children found that setting accounts for a significant proportion of the heterogeneity. The results showed that the mean difference was highest in North America. However, this variable was the same for each analysis from the same study and so some caution should be exercised in interpreting these results. Average temperature and age were also statistically significantly associated with the mean difference in the meta-regression of the mean difference in dmft/DMFT. Both of these variables showed a positive association with the mean difference. Temperature was the same for each analysis from the same study; this may be a particular problem for these data as the 16 measures included in the analysis came from only four studies, and so the results for this variable should also be interpreted with caution.

5. OBJECTIVE 2

If water fluoridation is shown to have beneficial effects, what is the effect over and above that offered by the use of alternative interventions and strategies?

Studies carried out after 1974 were selected to examine the effect of water fluoridation over and above the effect of other sources of fluoride, especially fluoridated toothpaste. As toothpaste containing fluoride was being widely used in industrialised countries by the early 1970’s, examining the effect of water fluoridation after 1974 should allow for any modifying effect of fluoride toothpaste and other sources of dental fluoride (e.g. mouthrinses, tablets) to be apparent. Studies carried out post-1974 which were conducted in industrialised countries were considered to have included the effects of these sources of fluoride, unless the study stated otherwise. Of the 24 studies that met the inclusion criteria for Objective 1, ten were completed after 1974 (1978 – 1997). The mean validity score of these ten studies is 5.0 (range 3.5 to 6.8 out of 8). Five of these studies were conducted in the UK (Wragg 1992; Attwood 1988; Hardwick 1982, Hobbs 1994; Gray 1999). The others were from the Netherlands, Finland, Germany, and Taiwan. Among these were eight before and after studies and two cohort study (Hardwick 1982, Maupomé 2000). Six of the before and after studies examined the discontinuation of water fluoridation.

The results of the studies in which fluoridation was initiated and which were completed after 1974 are displayed in Table 5.1. The results of the studies in which fluoridation was discontinued during this time period are presented in Table 5.2. In addition to the ten studies outlined above, two studies (Gray, 2000 and Holdcroft, 1999) met inclusion criteria but direct comparison data could not be extracted and were excluded from this table. The results of these studies can be found in Table 4.5 in chapter 4.

Table 5.1 Caries studies of fluoridation initiation, completed after 1974

Author (Year)	*Age*	**Teeth Type**	**Mean Difference** *(95% CI)*	*Year of final survey*	**Validity Score**
% Caries-free					
Guo (1984)	5 8 8 12 15	Primary Permanent Primary Permanent Permanent	**-2.0** (-6.4, 2.4) **64.1** (55.4, 72.8) **0.4** (-4.8, 5.6) **28.5** (20.5, 36.5) **34.4** (19.7, 49.1)	1971 - 1984	**4.8**
Gray (1999)	5	Primary	**26.0** (19.4, 32.6)	1988 - 1997	**3.5**
dmft/DMFT Score					
Guo (1984)	5 8 8 12 15	Primary Permanent Primary Permanent Permanent	**3.6** (2.6, 4.6) **1.6** (1.4, 1.8) **4.4** (3.9, 4.9) **2.6** (2.2, 3.0) **3.8** (2.7, 4.9)	1971 - 1984	**4.8**
Cohort Study: Difference in Increment in DMFS/DMFT score (Control – Fluoridated)					
Hardwick (1982)	12 12	Permanent Permanent	DMFS **2.5** (1.0, 3.9) DMFT **1.1** (0.4, 1.8)	1974 - 1978	**6.8**

Of the six studies assessing the proportion of caries-free children, five studies found the direction of association of water fluoridation and caries to be positive. Four of these found a statistically significant benefit. One study found the direction of association to be negative, but this effect was not statistically significant. All of the five analyses investigating the mean difference in dmft/DMFT were from the same study (Guo, 1984). All found a statistically significant positive association between water fluoridation and the mean difference in the change in dmft/DMFT. The cohort study of water fluoridation initiation found a statistically significant difference in the increment in both DMFT and

DMFS scores between the fluoridated and control area with the control area showing the greatest increment (Hardwick, 1982).

Table 5.2 Caries studies in which fluoridation was discontinued completed after 1974

Author (Year)	*Age*	**Teeth Type**	**Mean Difference (*95% CI)***	*Year of final survey*	**Validity Score**
proportion of caries-free children					
Kunzel (1997)	8 12 15	Permanent	**8.6** **-5.3** **-2.5**	1991 - 1995	**5.8**
Wragg (1992)	5	Primary	**-21.6** (-37.1, -16.3)	1985 – 1995	**4.5**
dmft/DMFT					
Attwood (1988)	10	Permanent	**-0.6** (-1.3, 0.1)	1980 – 1986	**4.8**
Hobbs (1994)	5	Primary	**-1.2**	1989 - 1993	**4.5**
Kalsbeek (1993)	15	Permanent	**-7.4** (-8.5, -6.3)	1968 – 1987	**5.5**
Kunzel (1997)	12 15 8	Permanent Permanent Permanent	**0.1** **-0.4** **0.3**	1991 - 1995	**5.8**
Wragg (1992)	5	Primary	**-1.5** (-2.2, -0.7)	1985 – 1995	**4.5**
DMFS score					
Kalsbeek (1993)	15	Permanent	**-18.8** (-21.3, -16.3)	1968 – 1987	**5.5**
Seppa (1998)	6 9 12 15	Not stated Permanent Permanent Permanent	**-0.1** **0.2** (-0.5, 0.9) **-1.1** (-2.3, 0.1) **-0.9** (-4.2, 2.4)	1992 - 1995	**5.8**
Mean Difference in D1D2MFS* Scores					
Maupomé (2000)	8 14	Permanent	0.59 (0.41, 0.77) 1.39 (0.23, 2.55)	**1993 – 1997**	**6.0**
D1D2MFS* Incidence					
Maupomé (2000)	11 17	Permanent	0.13 (-0.07, 0.34) 0.47 (-0.02, 0.96)	**1993 – 1997**	**6.0**

*D1D2MFS is a modified DMFS score where D1 = an incipient lesion, D2 = a cavitated lesion

There were 20 analyses looking at the discontinuation of water fluoridation, four of which looked at the proportion of caries-free children, seven looked at the dmft/DMFT score, five looked at the DMFS score and four reported on the D1D2MFS score. Of these 20 analyses, 12 found the direction of association to be positive (ie a greater increase in caries in the area that had been fluoridated compared with the control area). Twelve of the 20 analyses provided a measure of the significance of the association, four of the studies found a statistically significant positive association. Four analyses from a single study (Maupomé 2000) found the direction of association to be negative (the level of caries improved more in the area that discontinued fluoridation than in the area that was never fluoridated). Two of these results (from the before-after study but not in the cohort study) were statistically significant.

In the development of both of the meta-regression models of caries for Objective 1, the baseline disease level was included and found to be statistically significant. At lower levels of disease the reduction of dmft/DMFT was less in fluoridated areas than in non-fluoridated areas but there was a larger increase in the number of children found to be caries-free. Both of these differences were statistically significant. If other sources of fluoride are shown to have an effect on dental caries then decay should drop, thus baseline levels of decay would be at lower levels than when many of the original studies looking at water fluoridation were started. Water fluoridation would thus be expected to have less of an effect on the severity of dental caries, as measured by the dmft/DMFT score, but would be expected to have a greater effect on the proportion of caries-free children (see discussion section of chapter 4). Year of final study was also included as an explanatory variable in the univariate meta-regression for both the caries-free and dmft/DMFT analysis. This variable did not show any evidence of a significant association with the mean difference and so was not included in the multivariate analysis.

5.1 Discussion

This objective assesses the impact of water fluoridation on caries after the advent of other sources of fluoride, especially toothpaste containing fluoride. Relatively few studies qualified to address this issue (10). None of these identified this objective as the purpose of the study, but were conducted in time periods and countries where fluoridated toothpaste use was widespread. No included study specifically measured fluoride exposure from sources other than water although Hardwick (1982) reported the use of fluoridated toothpaste in both groups. The studies included for Objective 2 are a subset of those in Objective 1. The studies included in Objective 2 are of moderate quality (level B). Aside from design issues, their major failing was lack of analyses controlling for exposure to other sources of fluoride, including toothpaste.

While only ten studies were included for Objective 2, these would be enough to provide a confident answer to the objective's question if the studies were of sufficient quality. Since these studies were completed after 1974, one might expect that the validity assessments would be higher than the earlier studies due to the introduction of more rigorous study methodology and analytic techniques. However, the average validity checklist score and level of evidence was essentially the same for studies completed after 1974 as the whole group of caries studies. Hence, the ability to answer this objective is similar to that in Objective 1.

In examining the post-1974 studies (Table 5.1), the evidence suggests that water fluoridation has an effect over and above that of fluoridated toothpaste (and other sources of fluoride). If fluoridated toothpaste was responsible for reducing the difference in baseline caries between fluoridated and non-fluoridated areas, then the meta-regression models created for Objective 1 suggest that at lower levels of caries the reduction in DMFT would be less but the proportion of caries-free children would be greater. The study included in the review with the highest validity score (Hardwick 1982) showed a statistically significant difference in caries increment between fluoridated and non-fluoridated areas. Those in the non-fluoridated area had the greatest increment, in spite of fluoridated toothpaste being used by both groups (94% vs 95% used only fluoride toothpaste in the fluoridated and non-fluoridated groups, respectively).

6. OBJECTIVE 3

Determination of whether fluoridation results in a reduction of caries across social groups and between geographical locations bringing equity

No level A studies, and very few level B studies for Objective 3 were identified by the search. Because the issue of social class effects of water fluoridation was considered highly important, studies of any level that were conducted in the UK were included. A total of 15 studies investigating the association of water fluoridation, dental caries and social class were identified, ranging in publication dates from 1969-1999. Among these were three unpublished studies (Holdcroft 1999; Gray 2000, Jones 2000). Details of baseline information and results from each study can be found in tables in Appendix C. All but three of the included studies were cross-sectional in design. These three were before-after study designs (DHSS, 1969; Holdcroft, 1999; Gray, 2000). Seven of the studies presented measures of caries experience (proportion (%) of caries-free children, DMFT and dmft) stratified according to the Registrar General's social class classification (see Appendix H). Of these studies, five examined caries experience in children aged five, and two also examined 8, 12 and 14 year-olds. One study studied 10 year-olds only and another 15-16 year-olds only. Two studies presented data in a similar way but used different methods of classifying social class (low versus high deprivation and urban ordinary versus social priority). Urban ordinary and social priority was a classification used by the education authority to classify its schools at the time of the study, with social priority indicating less privileged students. Two studies used a regression analysis to investigate the association of caries experience (dmft and DMFT) with a measure of social deprivation (Jarman and Townsend scores, section 6.3), separately for high and low fluoride areas. The remaining two studies presented dmft and proportion caries-free data for a sample of fluoridated and non-fluoridated areas together with the Jarman score for each area, before and after water fluoridation was introduced in some of these areas.

If water fluoridation results in a reduction in caries across social class, reducing social inequalities in dental health, these studies would be expected to show that caries experience is lower in fluoridated than non-fluoridated areas. Importantly, the difference in caries experience between the social classes would be less in the fluoridated than in the non-fluoridated areas.

All except two of the studies investigating the association between caries experience, water fluoridation and social class were of evidence level C. The only exceptions were the before-after studies, which were level B. The average checklist score was 1.6 out of 8 (range 0.8 to 5.3), with eight of the 12 studies scoring only 0.8. Only two of the studies were prospective, had a baseline survey and follow-up and so the remaining studies lost marks for these checklist items. Only one study reported reliable measurement (or adequate reporting) of the fluoride concentration. None of the studies attempted to control for confounding using multivariate analysis – the only confounders considered were age (most studies presented results for one age only or stratified on age) and ethnic group (two of the studies only included children from one ethnic group).

Because there were very limited data available in formats that allowed pooling of results using meta-analytic techniques a more simple approach was adopted. For studies in which caries experience was presented by social class, as measured by the Registrar General's grouping, some pooling was possible and the results of this are presented below. For the other studies a qualitative analysis has been presented.

6.1 Proportion (%) of caries-free children stratified by the Registrar General's classification of social class

The proportion of caries-free children for each age group was determined by calculating the total number of children with no caries experience (caries-free), summing this number across studies and dividing by the sum of the total number of children from all studies. This method also allowed the calculation of a standard error and confidence interval. The results of this analysis are presented in Table 6.1. The studies included were Bradnock, 1984; Carmichael, 1980; DHSS, 1969; Evans, 1996;

Murray, 1984; and Murray, 1991. If there were several studies from one geographical area the most recent study for that age group was included. This decision was made in order to minimise the effect of any confounding variables operating in this area.

Table 6.1 Proportion of caries-free children by social class and water fluoride level

Fluoride level	Studies Included	Age	Social Class I & II		Social Class III		Social Class IV & V	
			% Caries-free (95 % CI)	Number	% Caries-free (95% CI)	Number	% Caries-free (95% CI)	Number
High	Bradnock 1984, Carmichael 1980, Evans 1996, DHSS 1969	5	73 (67, 79)	186	57 (52, 61)	453	53 (48, 57)	418
Low		5	55 (48, 63)	153	43 (37, 49)	289	37 (30, 44)	196
High	Murray 1984	10	43 (31, 55)	67	29 (23, 35)	249	30 (21, 39)	99
Low		10	26 (16, 36)	80	26 (20, 32)	225	23 (17, 29)	163
High	Murray 1991	15-16	31 (22, 40)	94	27 (20, 35)	135	23 (9, 37)	35
Low		15-16	23 (14, 32)	80	20 (13, 27)	140	25 (14, 36)	57

With the exception of one study of 15 to 16 year-old children (Murray 1991, social classes IV & V), these results show that for all age groups and all social classes the proportion of caries-free children is higher in the fluoridated than in the non-fluoridated areas. With the exception of the same study, caries experience is higher in the lower social classes (social class IV and V) than the higher social classes in both fluoridated and non-fluoridated areas. In most of the age groups, and for both high and low fluoride areas, a gradient relationship exists between social class and the proportion of caries-free children, this is illustrated graphically for children aged five in Figure 6.1. Data from children aged five years were graphed as four studies were included which looked at the association of water fluoride level, social class and caries experience in children of this age. Only two studies were found for other age groups, one each for ages 10 and 15-16.

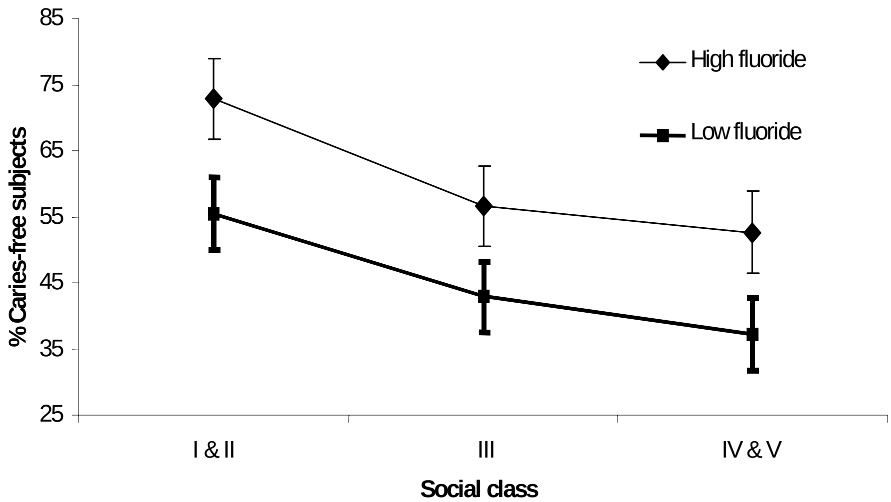

Figure 6.1 Proportion of (%) caries-free five-year-old children (95% CI) by social class in high and low fluoride areas

Figure 6.1 illustrates the higher proportion of caries-free children aged five years in the areas receiving fluoridated water compared with those receiving water with a low fluoride concentration. It also shows the increase in caries experience across the social classes for children aged 5 years. The absolute difference in the proportion (%) of caries-free children between Classes I & II and IV & V in the fluoridated group is 20%, while it is 18% in the non-fluoridated group. Thus there is no evidence from these studies to suggest that fluoridation reduces the social gradient.

6.2 dmft/DMFT stratified by the Registrar General's classification of social class

The mean number of dmft/DMFT per child for each age-group was determined by calculating the total dmft/DMFT in each study, summing this number across studies and dividing by the sum of the total number of children from all studies. This method did not allow the calculation of a standard error, and too many of the studies did not provide information on standard errors to allow this to be estimated. For children aged five, results from seven study analyses contributed to this analysis (from Bradnock 1984; Carmichael 1980; Carmichael 1989; DHSS 1969; and Evans 1996). For 8,12 and 14 year-olds, two analyses contributed (DHSS 1969, England and Wales data). However, for ages 10 and 15-16 data were only available from one study each (Murray 1984; Murray 1991). The results of this analysis are presented in Table 6.2.

Tables 6.2 dmft/DMFT by age, social class and water fluoride level

Fluoride level	Studies Included	Age	Social Class I & II		Social Class III		Social Class IV & V	
			DMFT	Number	DMFT	Number	DMFT	Number
High	Bradnock 1984; Carmichael 1980; Carmichael 1989; DHSS (England,) 1969; Evans 1996	**5**	1.1	343	1.9	388	1.8	227
Low		**5**	1.8	292	3.1	383	3.8	241
High	DHSS (England)	**8**	1.0	39	1.3	98	1.6	47
Low		**8**	1.2	49	2.0	88	2.2	37
High	Murray 1984	**10**	1.5	67	1.7	249	1.6	99
Low		**10**	1.8	80	2.0	225	2.0	163
High	DHSS (England)	**12**	3.6	15	3.5	47	3.5	17
Low		**12**	5.3	15	5.6	27	5.1	10
High	DHSS (England)	**14**	5.5	8	5.5	17	5.0	8
Low		**14**	6.8	13	7.8	29	6.5	8
High	Murray 1991	**15-16**	2.2	94	2.7	135	3.3	35
Low		**15-16**	2.9	80	3.4	140	3.9	57

These results show that for all age groups and all social classes the dmft/DMFT is lower in the fluoridated than in the non-fluoridated areas. On average there is more caries in the lower social classes (social class IV and V) than the higher social classes. In most of the age groups, and for both high and low fluoride areas, a gradient relationship exists between social class and the dmft/DMFT score, this is illustrated graphically for children aged five in Figure 6.2. As above children aged five were selected for further analysis as seven analyses were included for children of this age while data were only available from one or two analyses for each of the other age groups.

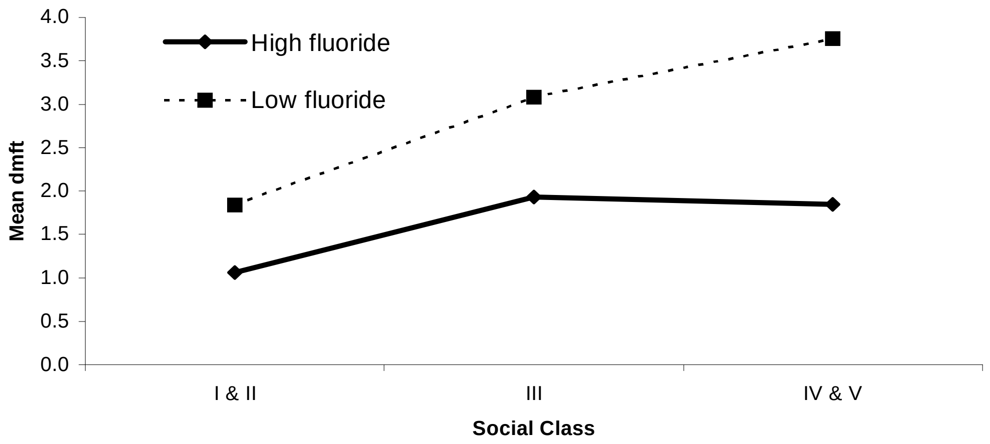

Figure 6.2 dmft by social class in high and low fluoride areas for children aged 5 years

Figure 6.2 illustrates the lower dmft in the areas receiving fluoridated water compared with those receiving water with a low fluoride concentration. It also shows the increase in caries experience across the social classes. The social class gradient is steeper in the low fluoride areas, in contrast to the proportion (%) of caries-free children graph. These data from 5-year-old children suggest that water fluoridation is leading to a decrease in dmft across the social classes and reducing the inequalities in dental health between the social classes. However this trend is not seen in the other age groups. It may be a finding peculiar to the younger age group or it may be because only a very small number of studies were included in the older age groups.

6.3 Other studies looking at dental decay, water fluoridation and social class

Two studies of five year-old children (Provart, 1995; and Rugg-Gunn, 1977) present results in a similar way to those outlined above but use different classifications of social class. The Provart study used the Townsend index (see Appendix H) to classify social deprivation, and then grouped the children into two groups, 'low' and 'high' deprivation. The cut-off used for this classification was not stated in the article. The Rugg-Gunn study used a classification system that was currently being used by the school system. Schools were classified as 'ordinary' or 'social priority'. Full details of these classifications were not given. These studies both show decreased caries experience in the fluoridated compared with the non-fluoridated areas. Comparing the fluoridated areas, Provart (1995) shows greater caries experience (measured by both dmft and proportion of caries-free children) in areas of 'high deprivation' compared with areas of 'low deprivation'. This finding is not confirmed by the Rugg-Gunn study, which did not find any difference in caries experience (deft and proportion of caries-free children) in areas defined as 'social priority' compared with areas defined as 'urban ordinary'.

A regression analysis approach was used in two studies, one of which was later re-analysed using a different measure of social deprivation (Riley, 1999; and Jones, 1997 and 2000). Riley selected five year-olds in seven fluoridated areas and seven non-fluoridated areas and calculated the slopes and intercept of the regression line, plotting mean dmft versus Townsend score for all fluoridated areas and all non-fluoridated areas. The slope of the regression line was positive in both groups of areas (the higher the deprivation scores the higher the dmft score) and the y intercept was lower in fluoridated areas (0.77 vs 1.7 for non-fluoridated areas). This means that the dmft experience is lower in fluoridated areas for all levels of deprivation. The slope of the regression line was statistically significantly less steep in the fluoridated areas than in the non-fluoridated areas (beta coefficient 0.08 vs 0.17, $p < 0.001$). This suggests that dental decay increases with increased social deprivation (as measured by the Townsend index), that dental decay is greater in non-fluoridated compared with fluoridated areas and that the *difference* in dental decay between the fluoridated and non-fluoridated areas increases with increased social deprivation.

The Jones 1997 study used data on five and 12 year-olds and calculated similar regression lines using the Jarman index. This study showed similar findings to the Riley study for dmft/DMFT scores. Dental decay had a significantly negative relationship with water fluoridation, and a significantly positive association with social deprivation. In this study, water fluoridation was also found to reduce the effect of deprivation. An unpublished report (Jones 2000) reassessed the impact of water fluoridation on caries by deprivation level using the same caries data for 12 year-old children, but classifying deprivation by the Townsend index rather than the Jarman index. The findings of the original study were confirmed, finding that the more deprived areas achieved greater reductions in tooth decay with water fluoridation than less deprived areas.

The Gray (2000) and Holdcroft (1999) reports present similar before-after data, comparing the dmft of children aged five before the introduction of water fluoridation in a selection of areas and 10 years after water fluoridation had been introduced. Jarman scores were presented for each area (based on the 1991 census). The authors have not presented enough suitable data for making comparisons. In particular, the areas that met inclusion criteria for having a baseline survey within one year of starting fluoridation were limited. In addition, none of the non-fluoridated areas presented had Jarman scores above zero, while the fluoridated areas had mixed Jarman scores. Matching fluoridated and non-fluoridated areas within these data sets is difficult due to the wide variation in Jarman scores, proportions of populations fluoridated, and starting dates of fluoridation.

The Beal 1971 study presents before and after data comparing the decayed, extracted and filled teeth (deft) and proportion of caries-free children aged five before the introduction of water fluoridation in two of three areas and three years later after water fluoridation had been introduced. One of the fluoridated areas is described as poorer and with a higher proportion of immigrants. The other two areas (one fluoridated, one not) are described as industrial areas. While there is no formal assessment of social class, the findings of this study are presented for comparison. The mean change in deft score in the poorer fluoridated area was larger than in the fluoridated industrial area (difference of 3.22 compared with 2.46). The change in the percent caries-free was also larger in the poorer group (difference of 39% compared with 13%). This implies that the effect is greater in the lower social classes.

6.4 Discussion

The number of UK studies with adequate social class data (15) was very small. Many other studies mentioned social class in some way, such as the typical occupations of the 'head of the house', or simply stated that social class in the areas being compared was similar. The quality of the evidence of the studies was low (all but 4 were level C), and the measures of social class that were used varied. Most of the studies that had enough information on social class to be evaluated were cross-sectional, with two before-after studies. Additionally, some of the included studies did not record individual exposure to water fluoride but were based on an ecological analysis, which is likely to be less accurate. Variance data were not reported for dmft/DMFT scores in these studies, so a statistical analysis was not undertaken. While these studies provide an indication of the effect, the ability to answer this question is low.

The effect of water fluoridation in reducing the difference in dental health between social classes classified by the Registrar General's classification shows varying effects. In the proportion of caries-free children analysis (Table 6.1 and Figure 6.1), a positive effect of water fluoridation is seen among children aged five years in all social classes. However, the difference between the classes does not vary between the high and low fluoride areas. In the mean change of dmft/DMFT analysis (Table 6.2 and Figure 6.2), water fluoridation does appear to be having an impact on reducing the differences between the social classes among children aged five years. In Figure 6.2 the slopes of the two lines are divergent, indicating a greater effect in the lower social classes (IV and V). This effect was not seen in 10 and 15-16 year-olds.

Two studies using regression analysis (presented in three analyses, Riley 1999; Jones 1997, Jones 2000) found similar effects on dmft/DMFT scores among five and 12 year-olds using measures of social deprivation (Townsend and Jarman indices) rather than the Registrar General's classification. These studies reported a statistically significant greater effect in the most deprived groups.

The meta-regression analysis reported in chapter 4 is also relevant to the discussion of the effect of water fluoridation on inequities in levels of dental caries. One of the findings of the social class studies is that people of lower social class had higher levels of dental caries. Thus their caries baseline score is higher. The results of the meta-regression analysis suggests that these children would have a higher reduction in mean dmft/DMFT but a lower reduction in the number of children who are caries-free. The meta-regression is based upon studies of stronger design than the majority of studies included in these analyses.

The small quantity of studies, differences between these studies, and their low quality rating, suggest *caution* in interpreting these results. There appears to be some evidence that water fluoridation reduces the inequalities in dental health across social classes in five and 12 year-olds, using the dmft/DMFT measure. This effect was not seen in the proportion of caries-free children among five year-olds. There were not sufficient data for the effects in children of other ages to be investigated fully.

Objective 4: Does water fluoridation have negative effects?

Any study of a potential negative effect of fluoridation that met inclusion criteria was reviewed. However, more studies were found and included on fluorosis, bone fracture, and cancer than other outcomes. This objective was broken down into four sections, fluorosis, bone fracture (and bone development effects), cancer and other possible adverse effects.

7. DENTAL FLUOROSIS

A total of 88 studies looking at the association of dental fluorosis with water fluoridation met inclusion criteria. Most of these studies examined children, but a few studied adults or did not state the age studied. Four of these studies used a before-after study design, one was a case-control study and the rest were cross-sectional studies in which the prevalence of dental fluorosis was measured at one point in time in areas with different water fluoride concentrations. Of these, 14 did not state whether the water was artificially or naturally fluoridated, 20 compared areas artificially fluoridated to a level of 0.6–1.2ppm with areas with low (<0.3ppm) or very high (4-7ppm) natural fluoride content. The remaining studies compared naturally fluoridated areas. These studies were conducted in 30 countries. For this analysis, study areas with natural fluoride levels above 5ppm were excluded. This is significantly above the level recommended for artificial fluoridation. The range of 0 to 5ppm is broad enough to be able to explore whether a dose-response relationship exists. Details of baseline information and results from each study can be found in the tables in Appendix C. Twelve studies met inclusion criteria but were not included in the main analysis for various reasons, the results of these studies and the reasons for their exclusion from the main analyses are presented in section 7.4.

One study achieved evidence level B, all of the remaining studies looking at dental fluorosis were of evidence level C. The validity scores ranged from 1.3 to 5.8 with a mean score of 2.8 out of a possible 8. Only one study included a baseline survey at the time of a change in the water fluoride level of one of the study areas (the level B study). Only four studies used a prospective study design and only 16 of the studies used any form of blinding.

Because the studies used different indices to assess fluorosis, the percentage prevalence of fluorosis was selected as the outcome of interest. Using this measure, all children with some degree of fluorosis were classified as 'fluorosed' as opposed to normal. Using the different indices, children with a TSIF, T&F or DDE score greater than zero and Dean's classification of 'questionable' or higher were classified as fluorosed. For the modified DDE index the number of children in the first category ('all') was taken as the number of children with dental fluorosis (see Appendix I). The term 'fluorosis' is used throughout this report, however it should be understood that the indices used to measure fluorosis also measure enamel opacities not caused by fluoride. Hence, the levels of fluorosis described here include some amount of overestimation of the prevalence of true fluorosis. This may be particularly true of those studies using the modified DDE index.

As there may be some debate about the significance of a fluorosis score at the lowest level of each index being used to define a person as 'fluorosed', a second method of determining the percent 'fluorosed' was selected. This method describes the number of children having dental fluorosis that may cause 'aesthetic concern'. The level at which fluorosis was judged to cause aesthetic concern was taken from a study by Hawley (1996). Children from Manchester aged 14 were shown pictures of fluorosis classified using the T & F index and asked to rate the appearance of each as either very poor, poor, acceptable, good or very good. The cut-off point for this analysis was taken as the level of fluorosis above which the children classified the photographs as "very poor" or "poor". This corresponded to a T & F score of three or more (Hawley, 1996). This was translated as being equivalent to Dean's score of "mild" or worse and a TSIF score of two or more. This additional analysis was restricted to these three indices, as the definition was not transferable to the other fluorosis indices.

A regression analysis was used to investigate the association of water fluoride level with the prevalence of dental fluorosis (the analysis was conducted separately for the two measures of fluorosis outlined above). A multilevel model was used to combine studies. Each area with a different fluoride concentration under observation within a study was included separately in the model. The log (odds) of having fluorosis/aesthetic fluorosis was modelled as a function of fluoride level. If the exact or average level of fluoridation was known this was included in the model. When a range of fluoridation level or an upper limit was provided the mid-value was used (for example if fluoridation was given as <0.7ppm, 0.35ppm was entered in the model for that group of people). When only a lower limit was given, 0.5ppm was added to this limit if it was less than 2ppm, and 1.0 was added if the limit was greater than 2ppm (e.g. if the level of fluoridation was given as >2.5ppm, then the level was entered as 3.5ppm). A sensitivity analysis was used to assess the robustness of the model's fit to the choice of values allotted to groups for which only lower limits were known. This was done by applying the lower limits themselves, and the lower limits +1.5ppm for levels with lower limits less than 2ppm, and 2ppm to groups with lower limits greater than 2ppm. The sensitivity analysis did not change the results of the analysis, so only the results of the main analyses are presented below.

The univariate regression model consisted of two parts. In the first, the standard fixed effect model, the log-odds of fluorosis was fitted as the outcome and the water fluoride level was fitted as the exposure variable. In the second, a random effects model was included to allow for the fact that some of the study areas came from the same studies (e.g. two low fluoride areas and four high fluoride areas from one study). Separate intercepts and slopes were permitted for each study by fitting these terms as random effects. In a similar fashion to more standard meta-analysis models, weighting of individual groups of people in the model was inversely proportional to the variance of the outcome estimate for that group. A normal distribution was assumed for the log odds for each group. Models were fitted using the 'PROC MIXED' procedure in the SAS software package, version 6.12 (SAS Institute Inc., USA). The algebraic form of the model used is presented in Appendix J.

The relationship between the *log* odds of aesthetic fluorosis and fluoride level appeared to be linear. However, the relationship between the *log* odds of fluorosis and the *log* of fluoride level appeared linear, and hence a log transformation of fluoride level was used in the model for this outcome. Both fluoride level and log fluoride level were centred before modelling.

A multivariate analysis was used to investigate possible sources of heterogeneity. This was similar to the univariate model in that it included two components, random and fixed effects. The effects of several potential factors were explored by including them as covariates in the above model. The effect of indices of fluorosis (e.g. Dean's), average age, source of fluoridated water (artificial, natural or both), mean altitude level, average temperature, type of teeth assessed (permanent, both, primary, not stated), method of assessment (clinical, photograph, both, not stated), study location (Europe, North America, S. America, Africa, Asia, Caribbean, Scandinavia, Australia), water source (public water, well, both, not stated), year of study report and study validity score were investigated.

The results of the analyses considering the proportion of people with any form of fluorosis and the proportion of people with fluorosis of aesthetic concern are presented separately.

7.1 Proportion of the population with dental fluorosis

7.1.1 Univariate analysis

The results of the univariate regression model are presented in Table 7.1

This model shows that log of the odds of the prevalence of dental fluorosis shows a positive linear association with the log of water fluoride level. Thus as water fluoride concentration increases so does the prevalence of dental fluorosis in the population. The random effects section of the model shows the variation between the intercepts and slopes fitted to the individual studies. Using this model, estimates with confidence intervals can be constructed for the proportion of persons in a population with fluorosis for a given level of water fluoridation.

Table 7.1 Results of the univariate analysis of the regression of water fluoride level against the proportion of the population with dental fluorosis

Variables	P-value individual parameters	Coefficient	Variance	Odds (95% CI)
Fixed effects				
Intercept	0.01	-0.440	0.030	0.644 (0.455 to 0.912)
Log fluoride level (centred by adding .526051)	0.0001	0.7155	0.0061	2.045 (1.750 to 2.390)
Random effects				
Between study (intercept)			2.024	
Between study (fluoride level – slope)			0.362	
Covariance of intercept and slope			-0.412	

This association is illustrated graphically in Figure 7.1. The size of the circles on the graph indicates the weighting of the study. Larger circles represent the larger studies.

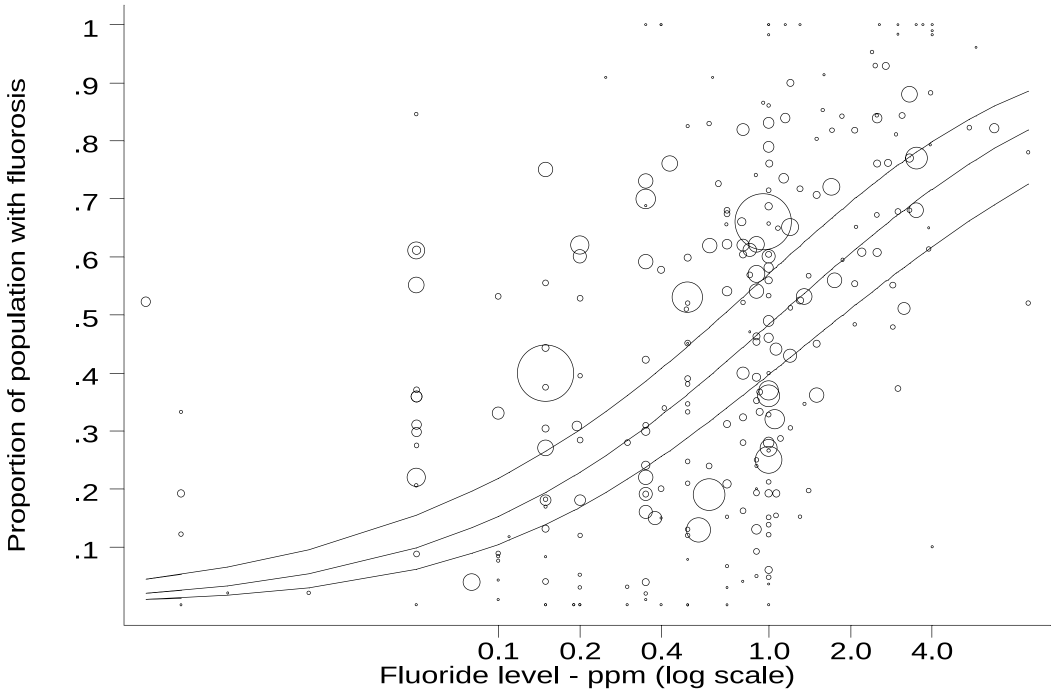

Figure 7.1 Proportion of the population with dental fluorosis by water fluoride level together with the 95% upper and lower confidence limits for the proportion

Examples of this model are illustrated in Table.7.2

Table 7.2 The estimated proportion (%) of the population with dental fluorosis at different water fluoride concentrations

Fluoride level	Proportion (%) of the population affected by dental fluorosis (95% CI)
0.1	15 (10, 22)
0.2	23 (17, 30)
0.4	33 (26, 41)
0.7	42 (34, 51)
1	48 (40, 57)
1.2	52 (43, 60)
2	61 (51, 69)
4	72 (62, 80)

These results show a strong association between water fluoride level and the proportion of the population with dental fluorosis. The model may not fit data at the extreme ends (low or high levels of fluoride) very well, due to the small numbers of data points. While many areas in Britain may have water fluoride levels lower than this, 0.4ppm has been chosen as the comparator (low fluoride) in subsequent analyses to ensure that the results are as reliable as possible. The effect of changing the water fluoride level of a low fluoride area with 0.4ppm fluoride in the water supply to an area with 0.7, 1.0 and 1.2ppm in the water supply is shown in Table 7.3

Table 7.3 Estimated difference in the proportion of the population with dental fluorosis at various levels of water fluoride concentration

Fluoride ppm	Difference in proportions (95% CI)
0.4 v 0.7	9.3 (-1.9, 20.6)
0.4 v 1.0	15.7 (4.1, 27.2)
0.4 v 1.2	18.9 (7.2, 30.6)

These results show that there are relatively large differences in the prevalence of dental fluorosis at the level of water fluoridation 0.7-1.2ppm when compared with an area with a relatively low water fluoride content (0.4 ppm). The differences in the prevalence of dental fluorosis at 1.0 and 1.2 compared with 0.4ppm are statistically significant (the confidence limits do not include 0). The numbers needed to harm (cause fluorosis) provide an estimate of the number of people that need to receive water fluoridated at the new level (compared to 0.4 ppm) for 1 extra person to have dental fluorosis. Increasing the level of water fluoride concentration from 0.4 to a slightly higher figure of 1.0 (the level which water is usually artificially fluoridated to) would lead to one extra person with dental fluorosis for every 6 people receiving the new higher level of water fluoride. In this case, the confidence interval ranges from 4 to 21 people. It must be remembered that these numbers are found when comparing to a theoretical low level of 0.4 ppm to 1.0 ppm, if the comparison level was lower the numbers needed to harm would be lower.

7.1.2 Multivariate analysis

The results of the multivariate analysis are presented in Table 7.4. All variables included in this model were statistically significant at the 5% level; all other variables which were investigated (see above) showed no statistically significant association at this level.

Table 7.4 Results of the multivariate analysis of the regression of water fluoride level against the proportion of the population with dental fluorosis

Variables	Parameter	P-value individual parameters	P-values Overall Variables	Coefficient	Variance	Odds (95% CI)
Fixed effects						
Intercept	Intercept	0.85		-0.069	0.146	0.933 (0.435 to 2.003)
Fluoride level	Fluoride level (ppm)	0.0001		0.718	0.006	2.050 (1.766 to 2.379)
Method of assessment	Clinical	0.77	0.0001	0.123	0.177	0.455 (0.220 to 0.943)
	Photograph	0.12		1.186	0.580	0.044 (0.007 to 0.275)
	Both	0.0001		2.582	0.432	0.005 (0.000 to 0.125)
	Not Stated	.		0	.	.
Teeth type	Permanent	0.04	0.0002	-0.787	0.138	1.131 (0.495 to 2.583)
	Both	0.001		-3.131	0.880	3.274 (0.736 to 14.571)
	Primary	0.002		-5.241	2.606	13.218 (3.642 to 47.977)
	Not Stated	.		0	.	.
Random effects						
Between study (intercept)					1.308	
Between study (fluoride level)					0.340	
Covariance of intercept & slope					-0.195	

These results show that the only variables to show a statistically significant association at the 5% level with the prevalence of dental fluorosis were water fluoride level, method of outcome assessment and teeth type. The odds of fluorosis were higher in studies using both a photographic and clinical assessment, compared with studies using a clinical or photographic examination and were slightly higher in studies using a photographic rather than a clinical assessment (in both high fluoride and low fluoride areas). This may be due to the drying of teeth before photographing them, allowing visualisation of more enamel defects. The odds of fluorosis were higher in permanent than primary teeth, and in studies looking at permanent teeth only compared with those looking at both permanent and primary dentitions. Controlling for these factors led to a small decrease in the between study variance for both the estimates of the intercept and slope. Some examples of the proportion of the population that would be predicted to have dental fluorosis at various levels of the exposures included in the final multivariate model are provided in Table 7.5.

Table 7.5 Multivariate model prediction of proportion of the population that would be expected to have dental fluorosis at various levels of exposure, method of measurement and teeth type

Fluoride level	Proportion (%) of the population with dental fluorosis (95% CI)
0.2ppm fluoride, identified clinically, both teeth types	2 (0, 11)
0.4ppm fluoride, identified clinically, both teeth types	3 (1, 17)
0.7ppm fluoride, identified using photograph, permanent teeth	61 (31, 85)
1.0ppm fluoride, identified using photograph, permanent teeth	67 (37, 88)
1.0ppm fluoride, identified using both methods of assessment, both teeth types	44 (12, 81)
2.0ppm fluoride, identified clinically, permanent teeth	54 (45, 62)

* both teeth types = permanent and primary teeth combined

7.2 Proportion of the population with dental fluorosis of aesthetic concern

7.2.1 Univariate analysis

The results of the model fitted in the univariate analysis are presented in Table 7.6

Table 7.6 Proportion of the population with dental fluorosis of aesthetic concern

Variables	P-value	Coefficient	Variance	Odds (95% CI)
Fixed effects				
Intercept	0.0001	-1.729	0.108	0.177 (0.091 to 0.346)
Fluoride level	0.0001	0.82985	0.0231	2.293 (1.685 to 3.120)
Random effects				
Between study (intercept) Sigma 2u			3.830	
Between study (fluoride level – slope) Sigma 2v			0.634	
Covariance of intercept and slope Sigmau v			0.113	

This shows that fluoride level has a statistically significant positive association with the prevalence of fluorosis of aesthetic concern. The between study variance in the estimate of the intercept slope of the regression line are higher than they were for the overall fluorosis analysis, indicating greater heterogeneity between studies. Using these model estimates, confidence intervals can be constructed for the proportion of persons in a population with fluorosis for a given level of water fluoridation (see Table 7.7).

Table 7.7 The proportion (%) of the population with dental fluorosis of aesthetic concern at different water fluoride concentrations

Fluoride level	% of the population affected by fluorosis of aesthetic concern (95% confidence interval)
0.1	6.3 (3.2, 12.4)
0.2	6.9 (3.5, 13.1)
0.4	8.2 (4.2, 14.9)
0.7	10.0 (5.0, 17.9)
1	12.5 (7.0, 21.5)
1.2	14.5 (8.2, 24.4)
2	24.7 (14.3, 39.4)
4	63.4 (37.9, 8.3)

This association is illustrated in Figure 7.2.

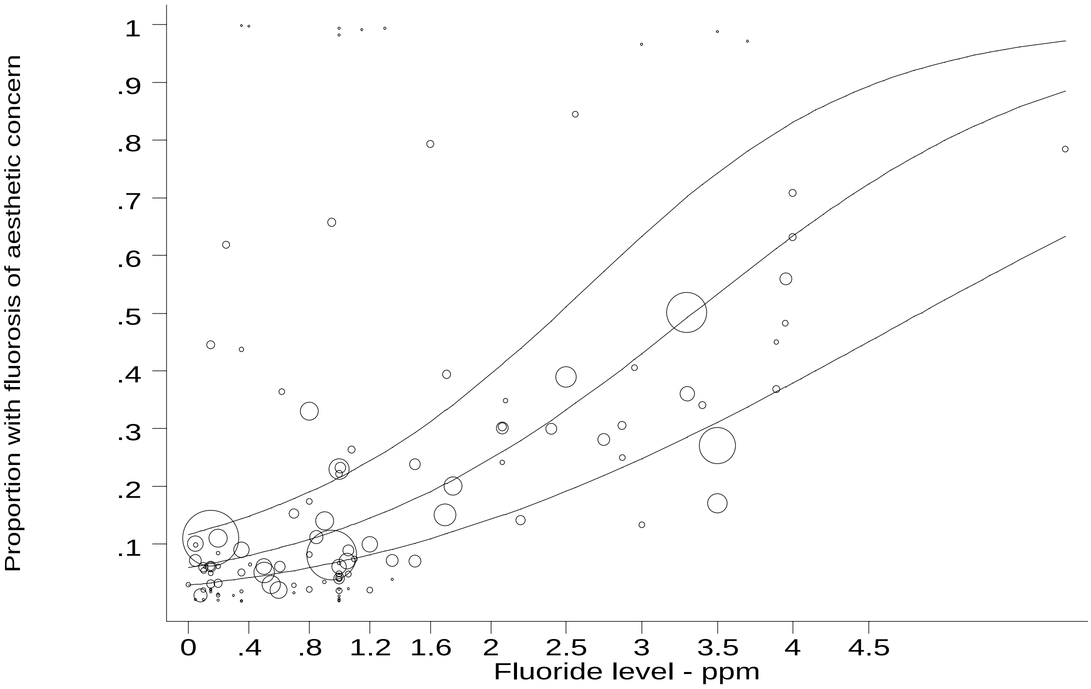

Figure 7.2 Proportion of the population with dental fluorosis of aesthetic concern by water fluoride level together with the 95% upper and lower confidence limits for the proportion

Figure 7.2 shows an increasing prevalence of fluorosis of aesthetic concern with increasing water fluoride level. The effect that changing the water fluoride level of a low fluoride area with 0.4ppm fluoride in the water supply to an area with 0.7, 1.0 and 1.2ppm in the water supply is shown in Table 7.8.

Table 7.8 Difference in the proportion of the population affected with fluorosis of aesthetic concern comparing a low level of water fluoride to levels around 1ppm

Fluoride ppm	Difference in proportions (%)
0.4 v 0.7	2.0 (-6 to 10)
0.4 v 1.0	4.5 (-4.5 to 13.6)
0.4 v 1.2	6.5 (-3.3 to 16.2)

The figures shown in Table 7.8 show that the difference between the proportion of the population affected with fluorosis of aesthetic concern at 0.4ppm compared with 0.7ppm is considerably lower than the difference in the proportion comparing 0.4ppm to 1.0ppm and 1.2ppm. Increasing the water fluoride level from 0.4 to 1.0ppm, the level to which water supplies are often artificially fluoridated, would mean that one additional person for every 22 people receiving water fluoridated to this level would have fluorosis of aesthetic concern. However, the confidence limits around this value include infinity, which means that it is possible that there is no risk. This is because the differences in proportions were not statistically significant (the confidence intervals include zero).

7.2.2 Multivariate analysis

The multivariate analysis of fluorosis of aesthetic concern is presented in Appendix K because the findings were similar to the findings on the primary analysis of fluorosis, section 7.1.2.

7.3 Sensitivity analysis

A sensitivity analysis of the regression analysis was conducted in which all data points above 1.5ppm were removed from the data set. It was suggested that the higher water fluoride levels were forcing the regression line to show a relationship that may not actually exist for the lower levels of fluoride. Restricting the analysis to levels less than 1.5ppm allowed the investigation of any association at these lower levels.

7.3.1 Fluorosis sensitivity analysis

The results of the univariate regression model are presented in Table 7.9.

Table 7.9 Results of the univariate regression of water fluoride level against the proportion of the population with dental fluorosis (sensitivity analysis)

Variables	P-value individual parameters	Coefficient	Variance	Odds (95% CI)
Fixed effects				
Intercept	0.01	-0.475	0.031	0.622 (0.437 to 0.885)
Log fluoride level (centred by adding .526051)	0.0001	0.5861	0.0070	1.797 (1.525 to 2.118)
Random effects				
Between study (intercept)			2.026	
Between study (fluoride level – slope)			0.349	
Covariance of intercept and slope			-0.338	

The model shows similar findings to the previous model (Table 7.1). The log of the odds of the prevalence of dental fluorosis continues to show a linear association with the log of water fluoride level. However, the gradient of the effect is slightly shallower (the increase in odds of fluorosis were 2.05 (95% CI: 1.75 to 2.39) in the first model and 1.80 (95% CI: 1.53 to 2.12) per unit increase of fluoride) in the sensitivity analysis.

Table 7.10 shows the estimates of the proportion (%) of the population with fluorosis at various water fluoride levels predicted by the model.

Table 7.10 Proportion of the population with dental fluorosis by water fluoride level together with the 95% upper and lower confidence limits for the proportion (sensitivity analysis)

Fluoride level	Proportion (%) of the population affected by fluorosis (95% CI)
0.1	18 (12, 26)
0.2	25 (18, 33)
0.4	33 (26, 41)
0.7	41 (33, 49)
1	46 (37, 55)
1.2	49 (40, 58)

The proportions of the population predicted to have fluorosis by this model are similar to the initial model in the lower water fluoride levels. However, the confidence intervals are larger. The graphical representation of this model is shown in Figure 7.3.

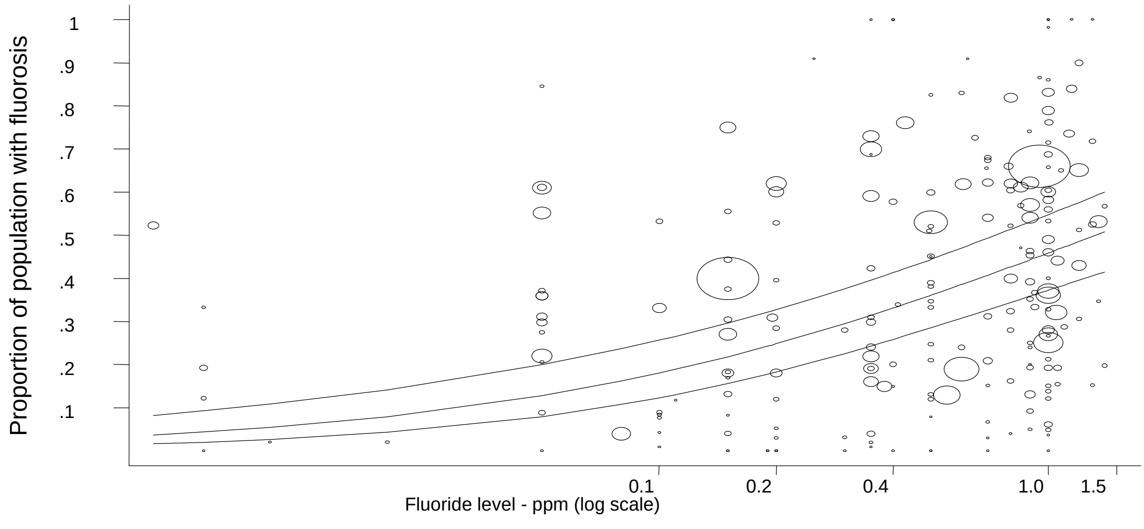

Figure 7.3 Proportion of the population with dental fluorosis by water fluoride level and predicted 95% confidence limits (sensitivity analysis)

7.3.2 Fluorosis of aesthetic concern sensitivity analysis

The results of the univariate regression model of fluorosis of aesthetic concern are presented in Table 7.11.

Table 7.11 Results of the univariate regression of water fluoride level against the proportion of the population with fluorosis of aesthetic concern (sensitivity analysis)

Variables	P-value	Coefficient	Variance	Odds (95% CI)
Fixed effects				
Intercept	0.0001	-1.953	0.130	0.142 (0.070 to 0.287)
Fluoride level (centred by subtracting 1.2565)	0.02	0.712	0.083	2.038 (1.159 to 3.583)
Random effects				
Between study (intercept)			4.117	
Between study (fluoride level – slope)			0.238	
Covariance of intercept and slope			1.657	

Similar to the original model, this model shows that fluoride level is statistically significantly associated with the prevalence of fluorosis of aesthetic concern. Again, the odds are slightly lower in this model, 0.14 (95% CI: 0.07 to 0.29), than in the original model, 0.18 (0.09 to 0.35). The predictions of the new model are given in Table 7.12.

Table 7.12 The proportion (%) of the population with dental fluorosis of aesthetic concern at different water fluoride concentrations

Fluoride level	% of the population affected by fluorosis of aesthetic concern (95% CI)
0.1	6 (2, 14)
0.2	6 (3, 14)
0.4	7 (3, 15)
0.7	9 (4, 17)
1	10 (5, 20)
1.2	12 (6, 22)

The point estimates here are slightly lower than in the original model (Table 7.6), but there is more uncertainty reflected in the larger confidence intervals. The graphical representation of the model is show in Figure 7.4.

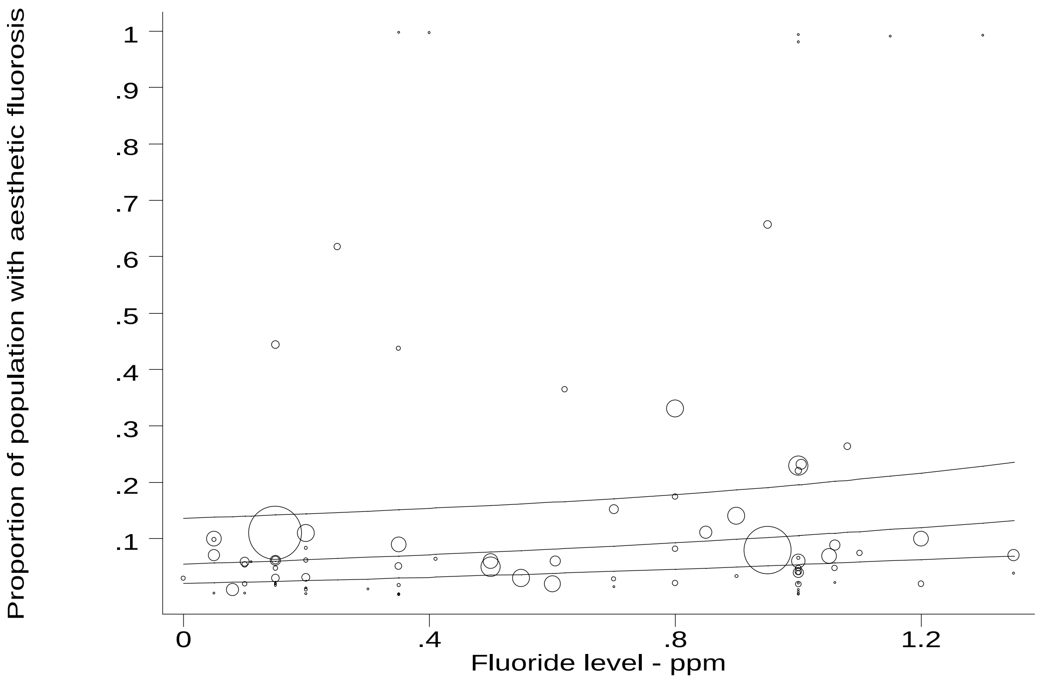

Figure 7.4 Proportion of the population with fluorosis of aesthetic concern by water fluoride level and predicted 95% Confidence Intervals

7.4 Studies that met inclusion criteria but were not included in the main analysis

The studies included in Table 7.13 were not included in the main analysis for the reasons outlined in the table. The conclusions of these studies appear to be compatible with the results of the main analysis of an increase in dental fluorosis with increased water fluoride concentration, so that their exclusion does not materially effect the result.

Table 7.13 Studies that met inclusion criteria but were not included in the main analysis

Author (Year)	Outcome	Reason for exclusion	Author's conclusions
Bhagan (1996)	Dental fluorosis	No separate results provided for control area – aggregate data only	The intensity of dental fluorosis is related to the concentration of fluoride in the water
Dissanayake (1979)	Dental fluorosis	The levels of fluoride in the **exposed groups** cover very wide ranges (0.3-3.8 and 0.3-4.6), which are very close to the levels of the control groups (< 0.2). These data can thus not be analysed in a meaningful way together with the other studies looking at fluorosis	Author does not make any conclusions regarding the incidence of dental fluorosis. Results indicate a considerably higher incidence of fluorosis in the areas with the higher ranges of fluoride concentrations in the water supplies
Forsman (1977)	Dental fluorosis	Different age groups are examined for the different fluoride exposure groups and so the results are not comparable between study areas	A greater proportion of children were affected by fluorosis in the higher fluoride area (2.75ppm) and fluorosis was also more severe in this area compared to the control areas (<1.5ppm)
Hellwig (1985)	Dental fluorosis	Children from naturally fluoridated areas combined with children from areas which changed from a low-fluoride supply to an optimally fluoridated supply 2 years prior to the examination– a significant proportion of the exposed group would not have been exposed to fluoride for enough time for a noticeable effect to have occurred	The incidence and severity of dental fluorosis was higher in the fluoridated areas compared to the control area
Larsen (1987)	Dental fluorosis	Measures of fluorosis are presented graphically for each tooth type. From these figures it is not possible to obtain an accurate reading.	The prevalence of dental fluorosis increases with the age during which the individual tooth is formed. The concentration of fluoride in the drinking water influenced the occurrence of fluorosis by resulting in a steeper profile of the prevalence from lower incisor to second molars rather than by increasing the prevalence for all teeth.
Latham (1967)	Dental fluorosis, nail mottling and prevalence of goitre	The results are not broken down as much as the water fluoride levels, giving very wide ranges of fluoride levels in some of the areas for which results are presented. All the areas are fluoridated at above 1ppm and some with fluoride levels as high as 45.5ppm	Author does not specifically relate results to water fluoride content of the area – he comments generally on the results seen in the whole sample studied, as all areas are exposed to comparatively high levels of fluoride. The incidence of dental fluorosis was high in all areas (>82%), as was the percentage of people with mottled nails (>26%), and the prevalence of goitre (12-41%). As these results are not specifically related to the water fluoride level and there was no control area it is difficult to link these findings to the water fluoride levels.

Author (Year)	Outcome	Reason for exclusion	Author's conclusions
Opinya (1991)	Dental fluorosis	Exposed area had fluoride level of 9ppm – considerably above level that would be encountered in artificially fluoridated area. Fluorosis data presented graphically for tooth type, not possible to obtain accurate data from the graphs	The incidence and severity of fluorosis was greater in the high fluoride area compared to the control area
Teng (1996)	Dental fluorosis	Areas selected because they were known to have a high incidence of fluorosis and then water fluoride level investigated. Reasons other than the fluoride content of the water are also investigated for the incidence of fluorosis.	Index of children's dental fluorosis has shown a decreased trend since the fluoride level of the water has been reduced
Gopalakrish-nan (1999)	Dental fluorosis	Areas selected because they were known to have a high incidence of fluorosis and then water fluoride level investigated. Reasons other than the fluoride content of the water are also investigated for the incidence of fluorosis.	Dental fluorosis is related to the high fluoride content of drinking water.
Morgan (1998)	Dental fluorosis and childhood behaviour problems	Children classified according to Dean's classification for fluorosis and then fluoride exposure examined. Childhood behaviour problems classified according to dental fluorosis levels not water fluoride levels.	The use of supplemental fluoride prior to age 3 was found to be a risk factor for dental fluorosis. No significant association was found between fluoride history variables in aggregate (including water fluoride level) and dental fluorosis. Dental fluorosis was not significantly associated with behaviour problems in the children studied

7.5 Prevalence of fluorosis over time

As with caries, the introduction of fluoride toothpaste in the 1970's could play a role in increasing the prevalence or degree of fluorosis occurring. Figure 7.5 presents the data on percent prevalence of fluorosis from 32 studies divided into before 1975 (23) and after 1985 (9), to allow sufficient time for fluorosis development after exposure to fluoridated toothpaste. These studies were conducted in nine countries (Australia, Canada, Finland, Ireland, Italy, New Zealand, Sweden, Britain, and the USA). Figure 7.5 is the main analysis measure of fluorosis; there were not enough data points to assess fluorosis of aesthetic concern. The bars represent different ranges of water fluoride (natural or artificial).

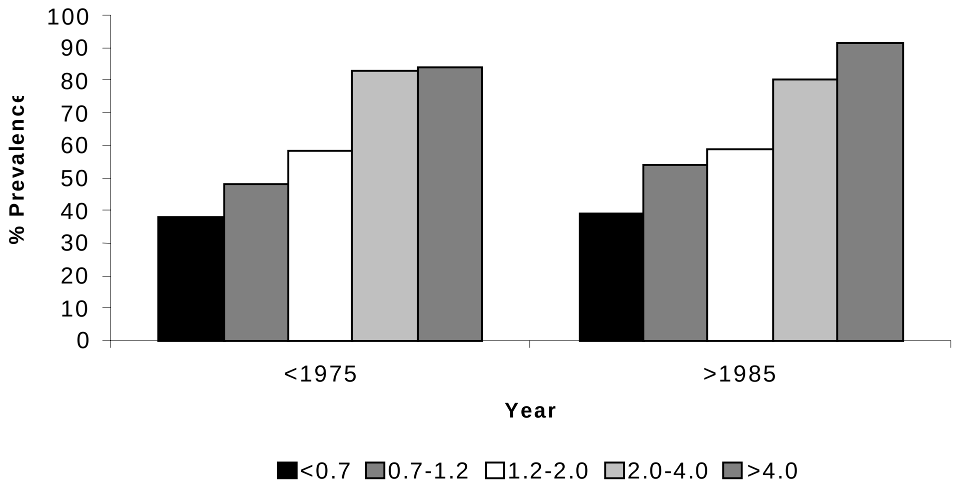

Figure 7.5 Prevalence of dental fluorosis at different water fluoride levels before 1975 and after 1985

Figure 7.5 shows similar patterns and prevalence of fluorosis both before 1975 and after 1985. An increase in the prevalence of fluorosis over time was not seen in this analysis of water fluoridation studies. While this finding is counterintuitive, no explanation is evident from these data. However, the measure of use of other fluoride sources was very crude.

Table 7.14 Studies that controlled for the effects of other fluoride use.

Author (Year)	Sources of fluoride	Other variables included in model	Classification of fluorosis	Results: Odds Ratio (95% CI)
Ismail (1990)	Fluoride tablet use	Type of school, city, sex, age	TSIF>=1	F tablet use = 1.70 (1.28, 2.27)
Riordan (1991)	Fluoride tablet use (short, medium and long term) versus no fluoride tablet use, likes toothpaste, started toothpaste < 1 year and 1-3 years versus >3 years, and swallowed toothpaste	Resident in fluoridated area for 1.2-4 years or 2.5-4 years versus <1 year	TF score >0	F tablets short: 1.55 (0.54, 4.42) F tablets medium: 0.87 (0.30, 2.52) F tablets long: 4.63 (1.97, 10.90) Likes toothpaste: 1.27 (0.75, 2.15) Started toothpaste <1 yr: 1.35 (0.72, 2.55) Started toothpaste 1-3 yr: 1.20 (0.63, 2.29) Swallowed toothpaste 1.02 (0.71, 1.45)
Szpunar (1988)	Fluoride rinse, use of fluoride supplements, dental attendance, age started brushing	Town, male education, age	Categorised as having fluorosis at TSIF>=1	Use of fluoride supplements, dental attendance, age started brushing not associated with fluorosis (no results presented). Fluoride rinse use = 1.57 (1.02, 2.41)
Brothwell (1999)	Fluoride supplements, fluoridated mouthwash, age parent brushed with fluoride paste,	Water fluoride level, breast feeding, highest level of education, household income	Categorised as having fluorosis at TSIF>=1	Fluoride supplements: 1.93 (1.02-3.62) Fluoride mouthwash: 2.73 (1.06-7.05) Age parent brushed: 0.93 (0.40-2.19)
Butler (1985)	Fluoride toothpaste, number of fluoride treatments, fluoride drops	Home air conditioning, race, total dissolved solids and zinc	CFI (Dean's community fluorosis index) stratified by exposure.	Use of fluoride toothpaste/drops and number of fluoride treatments almost identical in those that did and did not develop moderate fluorosis, therefore not included in multivariate analysis.
Heller (1997)	Fluoride drops, fluoride tablets, professional F treatment, school fluoride rinses	Water fluoride level, age	Fluorosis categorised as Dean's score of very mild or greater	Fluoride drops: 1.49 (1.11, 1.99) Fluoride tablets: 1.20 (0.96, 1.49) Professional F: 1.05 (0.85, 1.28) School fluoride rinse: 1.14 (0.84, 1.55)
Angelilo (1999)	Frequency of tooth brushing	Univariate analysis results presented	CFI (Dean's community fluorosis index) stratified by exposure.	Results presented as CFI (sd): Tooth-brushing < 1 day: 0.15 (0.31) > 1 day: 0.13 (0.37) No significant association so not included in multivariate analysis.
Kumar (1999)	Fluoride tablets and early brushing	Race and water fluoride level	Compared very mild or worse with normal.	Early brushing: 2.0 (1.2, 3.3) Fluoride tablet: 2.9 (1.3, 4.7) All compared to no fluoride exposure from any of these sources or from water fluoride.
Skotowski (1995)	Fluoride supplements, age started brushing, total toothpaste usage in 8 years, mouth rinse usage	Drinking water fluoride	Dental fluorosis present if received TSIF score>=1.	Fluoride-supplement use, mouth rinse use and age started brushing not significant in univariate analysis so not included in multivariate analysis. Fluoride exposure from toothpaste significant in univariate and multivariate analysis (adjusted OR not presented)

7.6 Possible confounding factors

There are likely to be many possible confounding factors in cross-sectional studies of dental fluorosis. Temperature and altitude are two that are frequently mentioned, but not controlled for in these studies. People living in climates with a higher mean temperature drink more water, thus being exposed to more total fluoride. Higher altitude has also been thought to be associated with the development of fluorosis, although the mechanism for this is unclear. Fluorosis can be difficult to distinguish from other developmental defects of enamel.

7.6.1 Studies which adjusted for the possible confounding effect of other sources of fluoride

Nine studies of the association between fluorosis and water fluoridation used multiple logistic regression analysis to control for the possible confounding effects of other sources of fluoride. The results of these analyses and the variables controlled for in the regression analysis are presented in Table 7.14. All results presented as adjusted odds ratios with 95% confidence intervals. These studies found mixed results, with no definite association between the other sources of fluoride studied and fluorosis.

7.7 Potential publication bias

The data were analysed in such a way that an measure of effect was not produced for each individual study thus it was not possible to investigate publication bias using standard methods.

7.8 Discussion

Fluorosis was the most widely and frequently studied of all the possible adverse effects considered. The fluorosis studies used cross-sectional designs, with a few before-after designs (again using different groups of people at each time point). The mean validity score was only 2.8 out of 8 and all but one of the studies were of evidence level C. Observer bias may be of particular importance in studies assessing fluorosis. Efforts to control for potential confounding factors, or reducing potential observer bias were infrequently undertaken. Seventy-two of 88 studies did not use any form of blinding of the assessor, and 50 of 88 did not control for confounding factors, other than by simple stratification by age or sex.

The primary fluorosis analysis was based on prevalence of ‘fluorosed’ people, including any degree of fluorosis. A conservative approach to defining fluorosis was used for this analysis, in that the ‘questionable’ category in Dean’s index was counted as fluorosis. Because there is evidence that very mild forms of fluorosis are not concerning to people (indeed some even preferred photographs of mildly fluorosed teeth) a secondary analysis assessed the prevalence of fluorosis of ‘aesthetic concern’.

With both methods of measuring the prevalence of fluorosis, a significant dose-response relationship was identified through the univariate regression analysis (Tables 7.1 and 7.6; Figures 7.1 and 7.2). The prevalence of fluorosis at a water fluoride level of 1.0ppm was estimated to be 48% (95% CI 40 to 57) for any fluorosis and 12.5% (95% CI 7.0, 21.5) for fluorosis of aesthetic concern. The numbers of additional people who would have to be exposed to water fluoride levels of 1.0 or 1.2ppm for one additional person to develop fluorosis of any level were quite low, 5 or 6 when comparing to a theoretical low fluoride level of 0.4ppm (Table 7.3). For fluorosis of aesthetic concern to occur in one additional person, however, the number was 22 at 1ppm, but the 95% CI included infinity (Table 7.8).

The multivariate analysis of fluorosis took into account variables potentially contributing to the heterogeneity between studies. This analysis found a statistically significantly higher risk in children with permanent teeth, compared with primary teeth or both types (Table 7.4). The multivariate analysis of fluorosis of aesthetic concern confirmed these findings (Appendix K). A sensitivity analysis limiting the range of water fluoride levels entered into the model did not alter the findings in any meaningful way.

The estimated NNT for one extra child to be caries-free (Chapter 4) was seven (95% CI 5 to 10), while the NNH for fluorosis is six (95% CI 4 to 21), with approximately a quarter of these being of aesthetic concern. These estimates are based on comparisons of specific levels of water fluoridation (e.g. < 0.7 ppm vs 0.7 to 1.2 ppm for caries, and 0.4 ppm vs 1.0 ppm for fluorosis). The numbers would change if different levels of fluoridation were compared.

Objective 4: Does water fluoridation have negative effects?

8. BONE FRACTURE AND BONE DEVELOPMENT PROBLEMS

A total of 29 studies of the effect of exposure to fluoridated water on bones met inclusion criteria. Among these were four prospective cohort studies, six retrospective cohort studies, 15 ecological studies, one case-control study, one study which used both a case-control and ecological design and two studies which met the inclusion criteria but was not included in the analysis for the reasons outlined in section 8.1. These papers studied a variety of fracture sites as well as slipped epiphysis in older children and young adults, and otosclerosis (malformation of bones in the ear). Hip fracture was included or was the only outcome in 18 studies. Details of baseline information and results from each study can be found in tables in Appendix C.

All but one of the studies looking at the association of water fluoride level with bone fractures were of evidence level C. The other study was of evidence level B, the average checklist score was 3.4 out of 8 (range 1.5 to 6.0). Only four of the 25 studies used a prospective study design, none used any form of blinding and only one study conducted a baseline examination prior to the introduction of fluoridation. The two lowest scoring studies did not address or control for any possible confounding factors. There were two case-control studies, both of which were of evidence level C, scoring 3.5 and 4 out of a possible 9 on the validity checklist.

Tables 8.1 to 8.4 present summaries of the findings of all eligible bone fracture studies included in the review, organised by fracture site or bone development problem. A point estimate of the size of the effect, the statistical significance of this measure and the study validity scores are also reported. In all calculations made by the review team, the area with the water fluoride level closest to 1.0 ppm was chosen and compared to the area with the lowest water fluoride level reported.

A forest plot of all the bone studies showing the measures of effect and their 95% confidence intervals was produced (Figure 8.1) for all studies that provided sufficient data to calculate a relative risk, odds-ratio or standardised rate-ratio and its 95% confidence interval. The majority of the measures of effect and their confidence intervals were distributed around 1, the line of no effect for related measures (suggesting no association), with no obvious outliers noted. The studies included in the forest plots differ from one another in a number of respects. Data are presented for both sexes, for different age groups and for different fracture sites (colour coded), using crude or adjusted outcomes and a variety of study designs.

In Figure 8.1, point estimates to the left of the vertical line indicate fewer fractures with exposure to fluoridated water, while those to the right side of the line indicate more fractures.

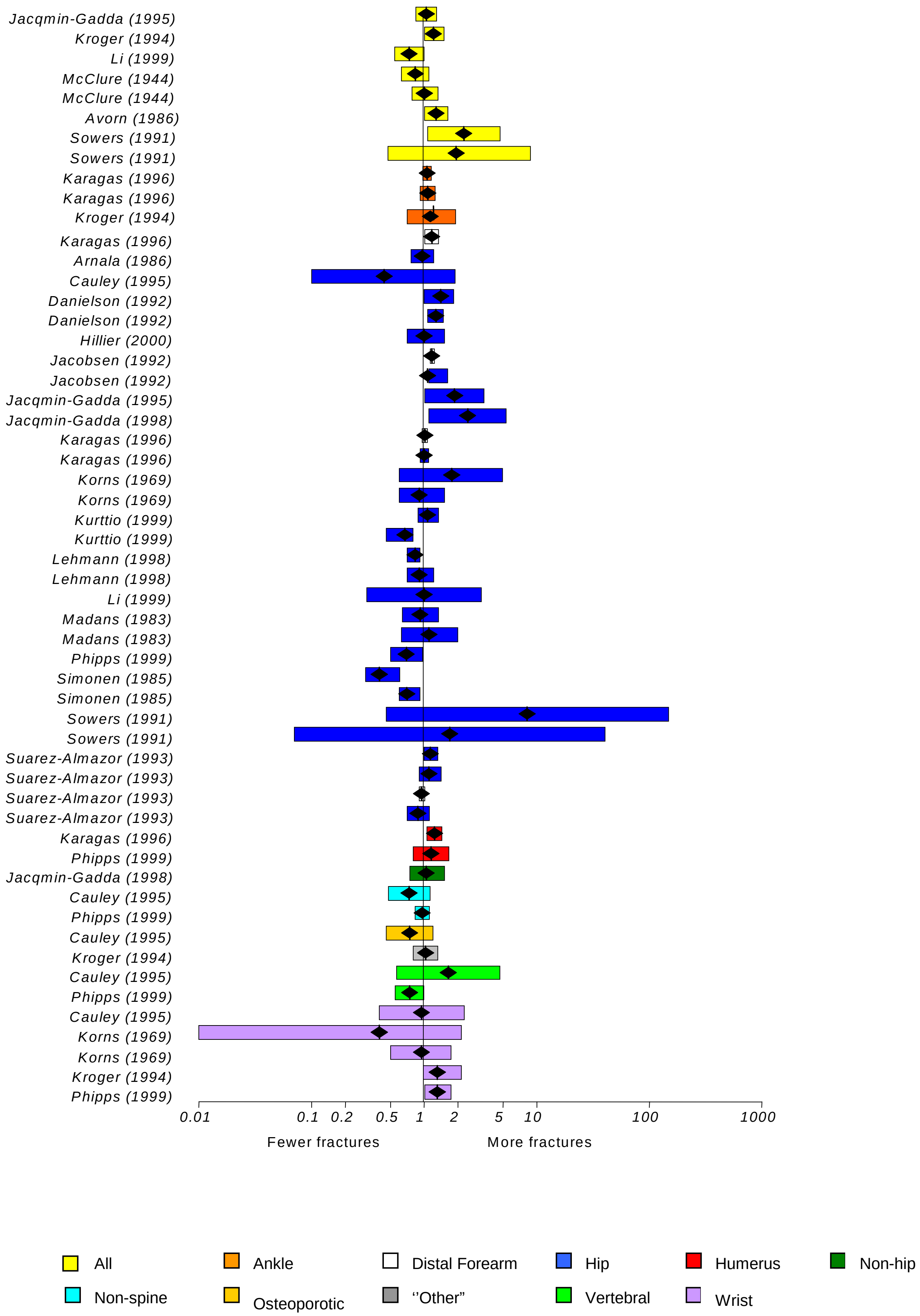

Figure 8.1 Bone fracture incidence (Measure of effect estimate and 95% CI)

Table 8.1 Effect of water fluoridation on hip fracture

Author (Year)	Age	Sex	RR (95% CI)	Validity score
Cauley (1995)	65+	Women	0.44 (0.1, 1.9)*	6.0
Jacqmin-Gadda (1998)	65+	Both	2.43 (1.1, 5.3)*	5.5
Sowers (1991)	20-35	Women	1.68 (0.07, 40.1)[1]	5.3
	55-80	Women	8.18 (0.46, 146.6)[1]	
Li (1999)	50+	Both	0.99 (0.3, 3.2)	5.0
Jacqmin-Gadda (1995)	65+	Both	1.86 (1.0, 3.4)*	5.0
Kurttio (1999)	50+	Women	1.08 (0.9, 1.3)*	4.5
	50+	Men	0.67 (0.5, 0.8)*	
Phipps (1999)	65+	Women	0.69 (0.5, 1.0)*	4.3
Hillier (2000)	50+	Both	1 (0.7, 1.5)*	4
Lehmann (1998)	35+	Women	0.83 (0.7, 0.9)	3.8
	35+	Men	0.91 (0.7, 1.2)	
Danielson (1992)	65+	Women	1.27 (1.1, 1.5)*	3.7
	65+	Men	1.41 (1.0, 1.8)*	
Jacobsen (1992)	65+	Women	1.08 (1.06, 1.10)	3.3
		Men	1.17 (1.13, 1.22)	
Cooper (1990)	45+	Both	R=0.41, p=0.009	3.3
Suarez-Almazor (1993)	45-64	Women	0.85 (0.7, 1.03)	3.0
	65+	Women	0.96 (0.9, 1.03)	
	45-64	Men	1.13 (1.0, 1.27)	
	65+	Men	1.07 (.087, 1.32)	
Madans (1983)	NS	Women	0.92 (0.6, 1.3)	2.8
	NS	Men	1.11 (0.6, 2.0)	
Simonen (1985)	50+	Women	0.7 (0.6, 0.9)*	2.5
	50+	Men	0.4 (0.3, 0.6)*	
Korns (1969)	40+	Men	1.75 (0.6, 4.9)	2.5
	40+	Women	0.91 (0.6, 1.5)	
Karagas (1996)	65+	Women	No association	1.5
Arnala (1986)	50+	Both	0.96 (0.8, 1.2)	1.5
	65+	Men	1 (0.9, 1.1)*	1.5

* = unadjusted **relative risk** ; RR = adjusted relative risk (see data extraction tables for further details of adjustment made in each study); [1] in the Sowers study there were no cases in the control group and so a Haldane approximation was used to estimate the relative risk.

A total of 18 studies (see Table 8.1) investigated the association of hip fracture with water fluoride level, making 30 analyses (e.g. men only, women only, both). Fourteen analyses found the direction of the association between water fluoridation and hip fracture to be positive (decreased hip fracture with increased water fluoride level). Five were statistically significant associations. Thirteen analyses found the direction of association to be negative (increased hip fracture), but only four of these found a statistically significant effect. Three additional analyses did not find any association. Three of the 18 studies found the direction of association positive in women but negative in men and one study found a negative effect in women and a positive effect in men.

There were no definite patterns of association for any of the fractures, for example, with all studies finding a positive effect for a particular fracture. A total of 30 analyses were conducted in 12 studies (see Table 8.2). Overall 14 analyses found the direction of association of water fluoridation and bone fracture to be negative (more fractures), of which one was statistically significant. Thirteen analyses found the direction of association to be positive (fewer fractures), of which one was statistically significant and two did not report variance data. Three analyses found no association. The two studies that found statistically significant effects were Li (1999), which found a small protective effect in both sexes for all fractures, while Karagas (1996) found a small negative effect in men for increased risk of fracture of the humerus. While both of these analyses were statistically significant, the 95% CI only just excluded 1.0.

Table 8.2 Effect of water fluoridation on other fractures

Author (Year)	Fracture	Age	Sex	RR (95% CI)	Validity Score
Sowers (1991)		20-35	Women	1.81 (0.5, 8.2)*	5.3
		55-80	Women	2.11 (1.0, 4.4)*	
Jacqmin-Gadda (1995)	All fractures	65+	Both	0.98 (0.8, 1.2)*	5.0
Li (1999)		50+	Both	0.69 (0.5, 0.9)	5.0
Avorn (1986)		65+	Women	1.2 (1.0, 1.5)	3.1
Kroger (1994)		47-56	Women	1.14 (0.9, 1.4)	2.8
McClure (1944)		19-23	Men	0.78 (0.6, 1.0)	2.8
		15-17	Men	0.95 (0.7, 1.2)	
Kroger (1994)	Ankle	47-56	Women	1.14 (0.7, 1.9)	2.8
Karagas (1996)		65+	Women	1 (0.9, 1.1)*	1.5
		65+	Men	1.01 (0.9, 1.2)*	
Bernstein (1966)	Collapsed vertebrae	45+	Women	0.26	3.5
		45+	Men	0.96	
Karagas (1996)	Distal forearm	65+	Women	Author states no association	1.5
		65+	Men	1.16 (1.0, 1.3)*	
Karagas (1996)	Humerus	65+	Women	Author states no association	1.5
		65+	Men	1.23 (1.1, 1.4)*	
Phipps (1999)		65+	Women	1.15 (0.8, 1.6)*	4.3
Jacqmin-Gadda (1998)	Non-hip	65+	Both	1.05 (0.7, 1.5)*	5.5
Cauley (1995)	Non-spine	65+	Women	0.73 (0.5, 1.1)*	6.0
Phipps (1999)		65+	Women	0.96 (0.8, 1.1)*	4.3
Cauley (1995)	Osteoporotic	65+	Women	0.74 (0.5, 1.2)*	6.0
Kroger (1994)	Other	47-56	Women	1.03 (0.8, 1.3)	2.8
Cauley (1995)	Vertebral	65+	Women	1.63 (0.6, 4.7)*	6.0
Phipps (1999)		65+	Women	0.74 (0.6, 1.0)*	4.3
Cauley (1995)	Wrist	65+	Women	0.95 (0.4, 2.3)*	6.0
Phipps (1999)		65+	Women	1.3 (1.0, 1.7)*	4.3
Kroger (1994)		47-56	Women	1.3 (1.0, 2.1)	2.8
Korns (1969)		40+	Men	0.4 (0.0, 2.1)	2.5
Korns (1969)		40+	Women	0.95 (0.5, 1.7)	

* = unadjusted relative risk ; RR = adjusted relative risk (see data extraction tables for further details of adjustment made in each study)

Three studies were included which examined the effects of water fluoridation on outcomes related to bone development (Table 8.3). Both studies of otosclerosis reported a beneficial effect of fluoridation, although no statistical analysis was presented. The study of slipped epiphyses found the direction of association to be positive (a protective effect) in girls and negative (increased risk) in boys, but neither of these was statistically significant at the 5% level.

Table 8.3 Effect of water fluoridation on bone development disorders

Author (Year)	Bone Development Defect	Age	Sex	RR (95% CI)	Validity Score
Karjalainen (1982)	Otosclerosis	All	Women	0.93	3.7
Daniel (1969)		All	Both	0.26	2.5
Kelsey (1971)	Slipped epiphysis	<25	Women	0.65 (0.4, 1.2)	3.8
			Men	1.2 (0.9, 1.6)	

8.1 Studies that met inclusion criteria but were not included in the main analysis

Two studies met inclusion criteria but were not included in the main analysis. Details of the studies and the reason for not including them in the main analysis are provided in Table 8.4.

Table 8.4 Studies which met inclusion criteria but were not included in the main analysis

Author (Year)	Outcome	Reason for exclusion	Author's Conclusions
Sowers (1986)	Bone fracture	The levels of fluoride in the control groups were similar to artificial levels of fluoridation. Women were classified according to water fluoride and calcium concentration. The high fluoride group (F level = 4ppm) was low in calcium and the lower fluoride groups (F level = 1pm) had very high and high levels of calcium in the water. This was likely to confound any association observed between water fluoride level and fracture incidence.	Intake of water providing ~4ppm of fluoride does not decrease fracture rate in young adult women or in postmenopausal women in a population-based setting. There was a history of more frequent fracture among women in the community with greater fluoride in drinking water as compared to women in the other 2 communities. Substantial fluoride intake may magnify the need for adequate dietary calcium and vitamin D intake, particularly in premenopausal women.
Horne (2000)	Bone fracture	Only the abstract was available. This did not provide sufficient details for inclusion of this study in the main analysis. The authors compared hip fractures and knee DJD joint replacements among those >65 years for 1991-1996 in a community with fluoridated water and 2 without. Directly standardised age-adjusted rates were calculated, these are not presented in the abstract. Only reports on one age-group which showed a significant association, results of other age-groups not presented and so it is not possible to draw conclusions from the limited results presented.	An association between fluoride and DJD of the knee was not supported, while a trend in the females for hip fracture was observed.

The level of water fluoride concentration examined in the Sowers (1986) study was higher than the level to which water supplies would be artificially fluoridated. The authors did not appear to find any significant association of fracture with water fluoride concentration, despite the possible confounding effect of the difference in calcium concentrations between the study areas. Full details of the Horne (2000) study were not available and the results presented in the abstract were insufficient for inclusion in the review or to draw any conclusions as to the results of this study.

8.2 Potential confounding factors

The incidence of hip fracture is strongly associated with age and sex, thus any study investigating the incidence of hip fracture should control for these variables. Other factors that may confound the association between water fluoride content and fracture incidence include body mass index (BMI), ethnicity, calcium intake, certain drugs, non-water fluoride exposure and the menopausal status of women. Of the 27 studies included in the analysis of water fluoridation and fracture incidence, 10 studies presented crude results only (some of these stratified on age and sex), 12 presented adjusted effect measures such as relative risks and odds ratios, and five studies presented standardised results. Of these, six studies failed to control for the effect of any possible confounding factors. Five studies presented results separately by sex and three studies controlled for age only (one of these controlled for age by only selecting people above a certain age). Five studies included only people within a certain age grouping and presented results by sex. Four studies controlled for the effects of both age and sex. Three studies controlled for age, sex and BMI and four studies controlled for other variables in addition to these three variables.

8.3 Meta-regression

Heterogenity was investigated using the Q statistic and found to be significant thus a meta-regression was carried out to investigate possible sources of heterogeneity between studies. Variables that may account for the differences in effect-size seen between studies were included in the regression model. The natural log of the outcome measure (relative risk, odds ratio or standardised rate ratio) was included as the dependent variable in the regression analysis. The results were then exponentiated to make the results more easy to interpret (see below for further details). The Haldane approximation was used to estimate variance where there were no cases in one of the groups. This involves adding 0.5 to the cells in a contingency table in which there are no cases.

Several of the studies included in the meta-regression contribute more than one estimate to the analysis. Some studies looked at different age groups or stratified results on sex and many of the studies looked at more than one fracture site. It has been assumed in this analysis that these subgroups of people are independent and hence each estimate has been treated as though it came from a separate study. The potential limitations of including these estimates in the same regression are discussed in section 12.6.

Continuous measures were centred on the mean (the mean value of each variable was subtracted from each of the individual measures), before including them in the regression model. Centring continuous variables in this way results in the constant (or intercept) of the regression model pertaining to the pooled estimate of the mean difference when the explanatory variable takes its mean value.

A univariate analysis was undertaken in which each of the variables was included individually in the regression model with the log of the relative risk, odds ratio or standardised rate ratio of the incidence of fracture in the fluoridated compared to the control study area. For studies that presented results for more than two study areas the comparison included in this analysis is the summary measure which compares the area with the fluoride level closest to 1ppm to the area with the lowest water fluoride level. If studies presented summary age-adjusted estimates in addition to age specific measures this estimate was included in the analysis, for studies in which no overall estimate was available age-specific or crude estimates were included.

A measure of the between study variance (heterogeneity) remaining after the variables included in the model had been accounted for was calculated using restrictive maximum likelihood estimation. Variables which showed a significant association with the outcome variable at the 15% significance level ($p<0.15$) in the univariate analysis were included in the multivariate analysis. The multivariate analysis was carried out using a step-down analysis in which each variable was included in the initial model. Variables were dropped one by one, with the variable that showed the least evidence of a significant association dropped first, until only variables which showed a significant association at the 5% level were included in the analysis. The analysis was repeated using step-up analysis to confirm the results of the step-down analysis. As a further exploratory analysis study validity was forced into the regression model as the effect of study validity was considered to be very important in these studies of variable quality.

8.3.1 Univariate analysis

The results of the univariate analysis are shown in Table 8.5. A total of 55 measure of effect estimates from 20 studies were included in the analysis.

At the 15% significance level the following variables showed a significant association with the summary measure: study duration and measure of exposure. These variables were included in the multivariate analysis. The model in which no variables (other than the outcome measure) were included shows the pooled estimate of the summary measure to be 1.00 (95% CI: 0.94, 1.06). This is the same as the measure that would be produced by a standard meta-analysis. The between study variance (heterogeneity) was investigated and found to be significant (Q statistic = 197 on 54 degrees of freedom, $p<0.001$). This pooled estimate suggests that there is no association between water fluoridation and fracture incidence. However, because of the significant heterogeneity this value should be interpreted with *extreme caution.*

Table 8.5 Results of the univariate meta-regression analysis for bone fractures

Variable	Category (number of analyses)	Constant (95% CI)	p-value of constant	Co-efficient (95% CI)	p-value of co-efficient	Between study variance
No variables (pooled estimate)		1.00 (0.94, 1.06)	0.926			0.029
Age	<35 (4)	0.89 (0.69, 1.14)	0.345			0.016
	35+ (6)			1.00 (0.73, 1.38)	0.983	
	45-65 (6)			1.21 (0.90, 1.62)	0.204	
	50+ (10)			0.91 (0.68, 1.21)	0.502	
	65+ (27)			1.20 (0.92, 1.56)	0.170	
	NS (2)			1.10 (0.71, 1.71)	0.660	
Study duration*	<5 (17)	1.04 (0.96, 1.13)	0.357			0.018
	5-10 (19)			1.03 (0.91, 1.17)	0.649	
	>10 (4)			0.69 (0.56, 0.84)	<0.001	
	Not stated (15)			0.90 (0.77, 1.04)	0.160	
Measure of* exposure	% exposed (10)	1.07 (0.95, 1.20)	0.271			0.028
	Water level (35)			0.92 (0.80, 1.07)	0.276	
	Years of exposure (10)			0.85 (0.69, 1.04)	0.118	
Highest estimate of water fluoride level	Low (2)	1.30 (0.84, 1.99)	0.236			0.030
	Optimum (49)			0.76 (0.20, 1.17)	0.214	
	High (4)			1.68 (0.75, 3.75)	0.205	
Outcome measure	Relative risk (48)	0.98 (0.91, 1.05)	0.512			0.030
	Odds Ratio (5)			1.19 (0.93, 1.52)	0.178	
	Standardised rate ratio (2)			1.15 (0.87, 1.53)	0.325	
Was an adjusted results presented?	No (18)	0.97 (0.86, 1.09)	0.594			0.030
	Yes (37)			1.04 (0.91, 1.20)	0.567	
Was the result adjusted for bmi?	No (45)	0.99 (0.93, 1.41)	0.855			0.031
	Yes (10)			1.03 (0.84, 1.27)	0.771	
Was the result adjusted for age?	No (20)	0.97 (0.86, 1.10)	0.652			0.031
	Yes (34)			1.03 (0.90, 1.19)	0.634	
	Matched (1)			1.03 (0.61, 1.74)	0.919	
Fracture site	Hip (27)	0.97 (0.89, 1.06)	0.549			0.032
	All (10)			1.03 (0.85, 1.25)	0.759	
	Wrist (5)			1.22 (0.90, 1.64)	0.200	
	Ankle (3)			1.05 (0.81, 1.36)	0.695	
	Distal forearm (1)			1.19 (0.81, 1.75)	0.374	
	Humerus (2)			1.23 (0.90, 1.69)	0.196	
	Non-hip (1)			1.08 (0.65, 1.79)	0.771	
	Non-spine (2)			0.90 (0.65, 1.25)	0.538	
	Osteoporotic (1)			0.76 (0.42, 1.38)	0.369	
	Other (1)			1.06 (0.68, 1.64)	0.800	
	Vertebral (2)			0.85 (0.55, 1.32)	0.472	
Was the result adjusted for sex?	No (5)	0.99 (0.81, 1.21)	0.917			0.032
	Yes (49)			1.01 (0.82, 1.24)	0.938	
	Matched (1)			1.01 (0.58, 1.76)	0.970	
Sex	Male (8)	1.00 (0.89, 1.11)	0.948			0.032
	Female (31)			1.00 (0.86, 1.15)	0.957	
	Both (16)			1.02 (0.82, 1.27)	0.832	
Validity*	3.65	0.99 (0.93, 1.06)	0.846	0.99 (0.94, 1.04)	0.748	0.030

*Included in multivariate analysis

8.3.2 Multivariate analysis

The multivariate model shows the effect of each variable controlled for the possible effects of the other variables included in the model. The results of the multivariate analysis are shown in Table 8.6. Study duration was the only variable to show a significant association at the 5% level with the summary measures (relative risk, odds ratio or standardised measure of effect) for the association of water fluoridation with bone fracture incidence. This variable reduced the between study variance from 0.029 to 0.018 in the final model. The analysis was repeated using a step-up analysis, this produced a similar model. This shows that the direction of association (non-significant) is negative (more fractures) for studies that last for less than five years and between five and 10 years and positive (fewer fractures) for studies in which duration is not stated. A statistically significant positive association was seen in studies that lasted for longer than 10 years, meaning that fewer fractures occur in fluoridated areas compared to non-fluoridated areas if they are studied longer than 10 years. Study validity did not show a statistically significant association with the measure of effect at the 5% level, and was not included in the multivariate model. The model with validity forced in is presented in Appendix L.

Table 8.6 Results of the multivariate meta-regression analysis for bone fracture studies

Variable	Category	Co-efficient (95% CI)	p-value	Between study variance
Constant		1.04 (0.96, 1.13)	0.357	0.018
Study duration	<5 (17)			
	5-10 (19)	1.03 (0.91, 1.17)	0.649	
	>10 (4)	0.69 (0.56, 0.84)	<0.001	
	Not stated (15)	0.90 (0.77, 1.04)	0.160	

8.4 Publication bias

A funnel plot to assess potential publication bias could not be constructed for bone fracture studies. The funnel plot graphs sample size versus measure of effect. The studies included in the meta-regression did not provide sufficient data on the sizes of the populations studied to make a plot. Because the measures of effect reported in these studies were distributed around 1, the line of no effect for relative measures, it would be unlikely that a funnel plot would be helpful in detecting potential publication bias. One additional study of osteoporotic bone fracture by Sowers, which included measurement of duration of residence, individual drinking water fluoride and serum fluoride levels, has been conducted. Communication with the author indicates that no association was found. However, while this study has been submitted to the Journal of Bone and Mineral Research, it has not yet been published.

8.5 Discussion

There were 29 studies included on bone fracture and bone development problems. Other than fluorosis, bone effects (not including bone cancers) were the most studied potential adverse effect. These bone studies also had low validity (3.4 out of 8) with all but one study being evidence level C. These studies included both retrospective and prospective cohort designs, some of which included appropriate analyses controlling for potential confounding factors. Observer bias could potentially play a role in bone fracture, depending on how the study is conducted.

The graph of estimates of association for all bone fracture studies (Figure 8.1) shows that the individual estimates of effect lie very close to a relative risk of 1.0. Most of the confidence intervals cross 1.0 (statistically non-significant). The only confidence intervals that do not include 1.0 (statistically significant) are evenly distributed, five indicating an increased risk of fracture and four indicating a decreased risk. The meta-regression showed that the pooled estimate of the association of bone fracture with water fluoridation was 1.00 (0.94, 1.06), however due to the significant heterogeneity between studies this value should be interpreted with extreme caution. The meta-regression showed that the only variable (out of 30 total) associated with the summary measure at the 5% significance level was study duration. Factors which would be expected to show an association with fracture incidence, such as fracture site, age and sex, were not associated with water fluoride level at the 5% significance level in either the univariate or multivariate models. This adds support to the result suggested by the pooled estimate of no association between water fluoridation and fracture incidence.

The evidence on bone fracture can be classified into hip fracture and other sites as there were a greater number of studies on hip fracture than any other site. Using a qualitative method of analysis, there is no clear association of hip fracture with water fluoridation (Table 8.5). Of 18 studies, three showed a statistically significant benefit, and two showed statistically significant harm, and three showed no effect of water fluoridation on hip fracture. One study found no cases of hip fracture in the low fluoride group, indicating harm from water fluoridation. The evidence on other fractures is similar (Table 8.2); of 30 study comparisons one found statistically significant benefit, one found statistically significant harm and three found no effect. The evidence on other bone outcomes was extremely limited. A negative association was suggested in the risk of slipped epiphysis in boys, but this finding was not statistically significant.

Objective 4: Does water fluoridation have negative effects?

CANCER STUDIES

A total of 26 studies examining the association between exposure to fluoridated water and cancer incidence and mortality met inclusion criteria; 10 before-after studies, 11 ecological studies, three case-control studies and two studies which met inclusion criteria but were not included in the main analysis for the reasons outlined in Table 9.4. These papers studied incidence and mortality from a variety of cancers, including all cancers, osteosarcoma, bone cancer, thyroid cancer and other site-specific cancers. Details of baseline information and results from each study can be found in tables in Appendix C.

Five of the studies of the association of cancer with water fluoride level achieved an evidence level of B (evidence of moderate quality, moderate risk of bias), the rest were of evidence level C (lowest quality of evidence, high risk of bias). The average validity checklist score was 3.8 out of 8 (range 2.8-4.8). For the three case-control studies the average score was 4.6 out of 9 (range 3.5 to 6.0). None of the included studies had a prospective follow-up or reported any form of blinding.

Analyses of cancer incidence and mortality data were identified for a variety of different cancers. The results of the studies considering all-cause cancer incidence and mortality and those that looked at osteosarcoma or bone and joint cancers, and thyroid cancer are presented below. All-cause cancer incidence is presented, as this is the outcome most commonly presented by the studies. The results of bone-cancer studies are also presented because if fluoride is linked to a site-specific cancer incidence, it is biologically plausible that this site would be affected because fluoride is taken up by bones. It has been suggested that fluoride may have an effect on the thyroid gland and for this reason studies which looked at cancer of the thyroid gland were also considered separately.

9.1 Cancer mortality from all causes

Table 9.1 shows the effect of fluoridation on all cause cancer incidence and mortality, a point estimate for this association, the measure used, and a measure of the significance of the association. Where studies presented an adjusted measure this is presented. For ecological or cohort studies that did not present an adjusted relative risk but did provide details on the number of cases and population at risk, an unadjusted relative risk was calculated. For studies that used an ecological or cohort study design that presented standardised mortality or incidence ratios (SMR/SIRs) the mean difference of the SMR/SIR was calculated together with the 95% confidence interval. For studies that used a before-after study design and presented relative risks or rate-ratios for two points in time the ratio of the summary measure comparing the final survey to the baseline survey was calculated. For studies that used a before-after study design and presented SMR/SIRs for both points in time, the difference of the change in SMR/SIRs from baseline to final survey between the fluoridated and control area was calculated. For studies that present a difference measure (e.g. mean difference) a negative result suggests a positive effect of fluoridation, and a positive result suggests a negative effect of fluoridation (i.e. greater cancer incidence in the fluoride group compared with the control group). For ratio measurements a ratio less than 1 suggests a positive effect of fluoridation and a ratio greater than one suggests a negative effect. If the confidence interval for this measure includes 1 or if the p-value is less than 0.05 then this suggests a statistically significant difference. In all calculations made by the review team, the area with the water fluoride level closest to 1.0 ppm was chosen and compared to the area with the lowest water fluoride level reported.

All cause cancer incidence and mortality was considered as an outcome in 10 studies, in which 22 analyses were made. Of these, 11 found the direction of association of water fluoridation and cancer to be positive (fewer cancers) and 9 found the direction of association to be negative (more cancers), 2 studies found no association of water fluoride exposure and cancer. One study (Lynch, 1985) found a statistically significant negative effect in 2 of the 8 sub-groups investigated; this was not confirmed when other sub-groups were considered (Appendix C). One study (Smith, 1980) found a statistically significant positive effect. There does not appear to be any association between validity and the direction of the association of water fluoride exposure and cancer incidence. Of the two studies with the highest validity scores (4.8 and 4.2) one found a statistically significant positive association (Smith, 1980) the other found a mixed effect (Lynch 1985); some analyses showed a statistically significant negative effect and others showing statistically non-significant associations in both directions. Overall these studies do not appear to show any association between overall cancer incidence and water fluoride exposure.

Table 9.1 Effect of fluoridation on cancer incidence and mortality

Author (Year)	Age	Sex	Summary measure	Results (95% CI)	Validity score
Smith (1980)	All ages	Both	Mean difference of change in SMRs	-4.4 (-7.5, -1.3)	4.8
Lynch (1985)	All ages	Male Female	Mean difference in SIRs	9.00 (p<0.001) 2.10 (p=0.592) -6.80 (p=0.057) -1.10 (p=0.500) 5.9 (p<0.001) 2.3 (p=0.565) 0.1 (p=1.000) 2 (p=0.630)	4.2
Chilvers (1983)	All ages	Both	Mean difference of change in SMRs	-0.1 (-3.8, 3.6)	3.8
Hoover (1976)	All ages	Male Female	Mean difference in SMRs	0 (-3.5, 3.5) 0 (-3.8, 3.8)	3.8
Chilvers (1985)	All ages All ages	Male Female	Mean difference in SMRs	-0.49 (-5.7, 4.8) -1.56 (-7.4, 4.3)	3.5
Goodall (1980)	Not stated	Male Female	Ratio of crude rate-ratios	0.85 0.90	3.5
Raman (1977)	All ages	Male	Mean difference of change in SMRs	6.9	3.3
		Female		18.9	
Cook-Mozaffari (1981)	All ages	Male	Ratio of Rate-Ratios	0.99	3.3
Richards (1979)	All ages	Both	Mean difference in SMRs	-3.3 (-18.7, 12.1)	3.1
Schlesinger (1956)	All ages	Male Female	Ratio of crude rate ratios	0.6 1.01	2.8

9.1.1 Studies of 20 US cities

Several studies presented analyses of data for the same set of cities in the USA, 10 fluoridated and 10 non-fluoridated cities (Table 9.2). These cities were originally selected and analysed by Yiamouyiannis (1977). The other studies present a re-analysis of the data included in this study, although some have selected slightly different years to investigate or have obtained data through different sources. All studies used before-after study designs comparing cancer incidence before and after the introduction of water fluoridation in 10 of the 20 study areas.

In the original study, Yiamouyiannis found a positive association between increased water fluoride and cancer incidence (more cancers). This study has been criticised for not taking into account demographic differences between the two groups of cities at baseline and inadequately accounting for changes in age (e.g. finer age bands) and gender structure between the baseline and final study years. Yiamouyiannis grouped men and women and whites and non-whites together into broad age groups (0-24, 25-44, etc) for the calculation of mortality ratios. The data show that the proportion of the populations that were non-white and over 65 years of age increased more rapidly in the fluoridated than in the non-fluoridated areas (Doll 1977).

The other studies use standardisation to control for age, sex and ethnic group. These studies did not find an association between cancer mortality and water fluoridation in the selected cities. Yiamouyiannis criticised the analysis used by Doll (1977) because the data used, supplied by the National Cancer Institute (NCI) contained a data transcription error which was repeated in the paper (Yiamouyiannis, 1977). Yiamouyiannis also argued that the analysis was inappropriate because 90-95% of the available data were omitted and that the selection of the year 1970 as one of the study years was inappropriate as fluoridation of the control group had already started. This had in fact only been started in two of the cities shortly (months) before the 1970 data were collected. Doll justified the choice of 1970 as a census year for which more accurate population data were available. Smith (1980) used the corrected NCI figures in a similar analysis and also failed to detect any association between water fluoridation and cancer mortality in the selected cities.

For the analysis presented here, the results of the four studies which analysed data for the same 20 US cities are presented together in Table 9.2. The study which scored the highest on the validity checklist, and did not include the error in the NCI data (Smith, 1980) is included in the main analysis in Table 9.1.

Table 9.2 Studies which present analyses of the same set of data for 20 cities in the USA

Author (Year)	Age	Sex	Summary measure	Results (95% CI)	Validity score
Doll (1977)	NS	Both	Mean difference of change in SMRs	-7.0 (-10.6, -3.4)	4.8
Chilvers (1982)	NS	Both	Mean difference of change in SMRs	-1.8 (-7.9, 4.2)	4.8
Smith (1980)	All ages	Both	Mean difference of change in SMRs	-4.4 (-7.5, -1.3)	4.8
Yiamouyiannis (1977)	0-24	Both	Ratio of crude rate ratios	1.01	4.1
	25-44			1	
	45-64			1.03	
	65+			1.03	

9.2 Osteosarcoma and bone cancer

Table 9.3 shows the association of osteosarcoma, bone and joint cancer incidence and mortality with water fluoride level, a point estimate of variance for this association, the measure used, and a measure of the significance of the association. Where studies presented an adjusted measure this is presented. For studies that did not present an adjusted relative risk but did provide details on the number of cases and population at risk, an unadjusted relative risk was calculated.

Table 9.3 Association of osteosarcoma, bone and joint cancer incidence and mortality with water fluoride level

Author (Year)	Age	Sex	Cancer	Summary measure	Results (95% CI)	Validity score
Kinlen (1975)	All ages	Both	Bone	Mean difference in SMRs	6 (-50.8, 62.8)	4.0
Hoover (1976)	All ages	Male	Bone	Mean difference in SMRs	0 (-35.9, 35.9)	3.8
		Female			20 (-22.6, 62.6)	
Hoover (1991)	All ages		Bone and joint	Mean difference of change in SIRs	1 (-30.2, 32.2)	3.3
Mahoney (1991)	<30	Male	Bone	Crude RR	0.93	2.8
	<30	Female			0.96	
	30+	Male			0.84	
	30+	Female			1.1	
Moss (1995)	Not stated	Both	Osteosarcoma	OR	1.0 (0.6, 1.5)	6.0
Gelberg (1995)	<24		Osteosarcoma	OR	2.07 (0.5, 8.0)	4.3
	<24			OR	1.84 (0.8, 4.2)	
Hrudey (1990)	All ages		Osteosarcoma	Crude RR	0.93 (0.6, 1.6)	4.0
Hoover (1991)	All ages		Osteosarcoma	Mean difference of change in SIRs	-11 (-44.6, 22.6)	3.8
McGuire (1991)	0-40	Both	Osteosarcoma	OR	0.33 (0.0, 2.5)	3.5
Mahoney (1991)	<30	Male	Osteosarcoma	Crude RR	0.98	2.8
	<30	Female			0.78	
	30+	Male			0.88	
	30+	Female			0.91	
Cohn (1992)	0- 20	Male Female	Osteosarcoma	Crude RR	3.4 (1.4, 8.1) 1.0 (0.3, 3.5)	2.5

Four studies considered the association of bone related cancer and water fluoride exposure, performing eight analyses. Of these, the direction of association of water fluoridation and bone cancer was found to be positive in three, negative in four and one did not detect a relationship. None of the studies found a statistically significant association, however one study (Mahoney 1991) contributed five of the nine analyses with no variance data.

Seven studies of osteosarcoma, presenting 12 analyses were included. Of these, the direction of association between water fluoridation and osteosarcoma incidence or mortality was found to be positive (fewer cancers) in seven, negative (more cancers) in threeand two found no relationship. Of the six studies that presented variance data, one (Cohn 1992) found a statistically significant association between fluoridation and increased prevalence of osteosarcoma in males. This study however, also had the lowest validity score, 2.5 out of 8. One study (Mahoney 1991) contributed four of the 12 analyses but did not provide variance data.

9.3 Cancer of the thyroid gland

Two studies (Kinlen 1975, Hoover 1976) investigated the association of water fluoride level with cancer of the thyroid gland. Both studies used indirect standardisation to control for the effects of age and sex and did not find any association between water fluoride level and thyroid cancer (Appendix C).

9.4 Studies that met the inclusion criteria but were not included in the main analysis

The studies in table 9.4 met the inclusion criteria but were not included in the main analysis for the reasons outlined in the table. Both of these studies appear to confirm the results of the main analysis: a lack of association between water fluoride content and cancer incidence and mortality.

Table 9.4 Studies that met the inclusion criteria but were not included in the main analysis

Author (Year)	Outcome	Reason	Authors Conclusions
Hoover (1990)	Cancer Mortality	Non-fluoridated areas grouped together with areas fluoridated within the past five years.	The relative risk of death from cancers of the bones and joints was the same after 20-35 years of fluoridation as it was in the years immediately preceding fluoridation. A similar lack of relationship to timing of fluoridation was noted for the incidence of bone and joint cancers and osteosarcomas. The relative risk of developing these cancers 20 or more years after fluoridation was lower than the risk associated with less than five years of fluoridation among both males and females. For no type of malignancy was there consistent evidence of a relationship with patterns of fluoride. In a study of over 2300000 cancer deaths in fluoridated counties across the US, and over 125000 incident cancer cases in fluoridated counties covered by two population based cancer registries, no trends in cancer risk that could be ascribed to the consumption of fluoridated drinking water could be identified.
Swanb erg (1953)	Cancer Mortality	Cancer mortality compared between fluoridated area and the whole of the US - includes areas with fluoride in the water supplies and so not a suitable control area	The death rate from cancer in the study area decreased during the study period whereas the death rate from cancer in the whole of the US (the control area) increased over the same period.

9.5 Possible confounding factors

There is a dramatic increase in cancer with age and a considerable difference in cancer mortality between men and women and among different ethnic groups, thus even small differences in the age, sex and ethnic structure of a population can lead to noticeable differences in cancer incidence. Any study looking at the association of cancer with different exposures should therefore control for these confounding factors in the analysis. There are numerous other factors that may also lead to differences in cancer incidence between populations if the exposure of populations differ, for example, smoking, social class, diet and environmental factors, including exposure to other sources of fluoride. Of the 26 cancer studies in the main analysis, 12 used standardisation (11 used the indirect and one the direct method) to control for age and sex (some studies presented results separately by sex) and four of these also controlled for ethnic group. One study presented an age adjusted rate, and five studies presented crude data only. Of the three case-control studies, one presented a crude odds ratio matched on age, gender and county of residence, one presented an odds ratio with cases and controls matched on sex and year of birth (age). The third matched cases and controls on age, sex and race and then presented an odds ratio adjusted for population size, age radiation exposure and gender.

9.6 Discussion

The evidence of the effect of water fluoridation on cancer was of the highest quality available under Objective 4 (3.8 out of 8 compared with a mean of 2.7 for other possible negative effects) but was still only low to moderate. Twenty-one of the 26 studies presented are from the lowest level of evidence (level C) with the highest risk of bias. While prospective study designs may be more difficult to conduct in cancer studies due to long incubation periods and rarity of some cancers, they are possible. Blinding of outcome assessment to exposure is certainly possible in such studies, for example outcomes assessed using published sources could blind investigators to fluoride levels in the study areas.

There is no clear picture of association between water fluoridation and overall cancer incidence and mortality (Table 9.1). Whilst there were 11 analyses that found the direction of association of water fluoridation and cancer to be positive (fewer cancers), a further nine analyses found a negative direction of association (more cancers), and two studies found no effect. Only two studies found statistical significance, both suggesting an association in different directions. One of these studies contained eight analyses of which only two found a statistically significant adverse effect of water fluoridation.

While a broad number of cancers were represented in the included studies, osteosarcoma, bone/joint and thyroid cancers were of particular concern due to fluoride uptake by bone and thyroid. Again, no clear association between water fluoridation and increased incidence or mortality was apparent. Of eight analyses from the six studies of osteosarcoma and water fluoridation reporting variance data, none found statistically significant differences. Thyroid cancer was also considered but only two studies examined this and neither found a statistically significant association with water fluoride level.

The findings of cancer studies were mixed, with small variations on either side of no effect. Individual cancers examined were bone cancers and thyroid cancer, where once again no clear pattern of association was seen. Overall, from the research evidence presented no association was detected between water fluoridation and mortality from any cancer, or from bone or thyroid cancers specifically.

Objective 4: Does water fluoridation have negative effects?

10. OTHER POSSIBLE NEGATIVE EFFECTS

A total of 33 studies of the association of water fluoridation with other possible negative effects were included in the review. There were six before and after studies, one retrospective cohort study, 12 ecological studies, five cross sectional, one case control study and eight studies which met inclusion criteria but were not included in the main analysis for reasons outlined below (Table 10.3 and section 10.2). These studies examined a variety of different outcomes including Down's syndrome, mortality, senile dementia, goitre and IQ. Details of baseline information and results from each study can be found in tables in Appendix C. Two studies (Briner 1966 and Schatz 1976) presented data from the same two cities in Chile from similar time periods. To avoid duplication, only the Schatz study is presented in the tables below, but both studies are included in the data tables in Appendix C. Although some authors (Spittle 1993) have reported cases of hypersensitivity to fluoridated water, no studies meeting the inclusion criteria were found.

The quality of these studies was generally low; all studies were of evidence level C (lowest quality of evidence, high risk of bias). The average validity checklist score was 2.7 out of 8 (range 1.5-4.5). None of the studies had a prospective follow up or incorporated any form of blinding. Whilst the one case control study (Dick, 1999) achieved a validity checklist score of 7 out of 9, it should be noted that this study was also of evidence level C.

Table 10.1 shows the effect of water fluoridation on all potential adverse outcomes (other than fluorosis, bone fracture and cancer) reported in the studies included. A point estimate for this association, the measure used and a measure of the significance of the association is presented. Where studies reported an adjusted measure, this is presented. For studies that did not present an adjusted relative risk but did provide details on the number of people studied and population at risk, an unadjusted relative risk was calculated from these data.

For studies that present a difference measure (e.g. mean difference) a negative result suggests a benefit of fluoridation, and a positive result suggests harm from fluoridation (i.e. greater cancer incidence in the fluoride group compared with the control group). For ratio measurements a ratio less than 1 suggests a benefit of fluoridation and a ratio greater than one suggests harm. If the confidence interval for this measure includes 1 or if the p-value is less than 0.05 then this suggests a statistically significant difference.

Only three studies showed a statistically significant effect at the 5% level. Forbes (1997), found a statistically significant negative effect of water fluoride on Alzheimer's disease (increased incidence) and a statistically significant positive effect on impaired mental functioning (decreased incidence). Erickson (1976) found a statistically significant positive association with congenital malformations in one of two sets of data but not in the other. Lin (1991) found statistically significant negative association of combined low-iodine/high fluoride with goitre and mental retardation. Age at menarche, anaemia during pregnancy and sudden infant death syndrome (SIDS) did not show statistically significant associations with water fluoride exposure. The direction of association of primary degenerative dementia (Still 1980) and cognitive impairment (Jacqmin-Gadda 1994) with water fluoridation was positive (fewer cases) but no measure of the statistical significance of this effect was provided. Skeletal fluorosis and IQ both found the direction of association with water fluoride to be negative, but again no measure of the statistical significance of this association was presented.

Five studies examined the association between all cause mortality and water fluoride exposure. Three studies found the direction of association of water fluoridation and mortality to be negative (more deaths), one found the direction of association to be positive (fewer deaths) and one found no association. Once again, no measures of the statistical significance of these associations were provided. However, for two of the studies that found a negative direction of association, the point estimate was 1.01, which is unlikely to have reflected a statistically significant effect. Three studies examined the association between infant mortality and water fluoride level. All three studies found a negative direction of association, but again no measure of the statistical significance of this association was presented and so it is difficult to draw conclusions from these results.

Table 10.1 Association of various adverse effects with water fluoride level

Author (Year)	*Outcome*	*Age*	Sex	Summary measure	Results (95% CI)	Validity score
Forbes (1997)	Alzheimer's disease	76	Both	Adjusted odds ratio	1.22 (1.0-1.5)	4.0
	Impaired mental functioning				0.49 (0.3-0.9)	
Still (1980)	Primary degenerative dementia	55+	Both	Crude RR	0.18	3.0
Jacqmin-Gadda (1994)	Cognitive impairment	>= 65	Both	Crude RR	0.93	4.5
Griffith (1963)	Anaemia during pregnancy	Not stated	Women	Rate difference	2.03 (-5.0-9.0)	2.3
Farkas (1983)	Age at menarche	7-18	Girls	Mean difference	0	1.5
Erickson (1976)	Congenital malformations		Both	Crude RR	1.08 (p>0.05) 0.95 (p<0.05)	3.5
	Down's syndrome				1.16 (p>0.05) 0.96 (p>0.05)	
Erickson (1980)	Congenital malformations		Both	Crude RR	1.00 (0.9-1.1)	3.5
	Down's syndrome				0.93 (0.7, 1.2)	
Berry (1958)	Down's syndrome		Both	Crude RR	0.84-1.48	1.8
Needleman (1974)	Down's syndrome		Both	Crude RR	1.14	2.0
Rapaport (1957)**	Down's syndrome		Both	Crude RR	1.5	2.0
					2.3	
					2.2	
					2.2	
Rapaport (1963)	Down's syndrome		Both	Crude RR	3.0	2.0
	Infant mortality				1.3	
Dick (1999)	Sudden Infant Death Syndrome	Not stated	Both	Odds ratio	1.19 (0.8, 1.7)	7 (of 9)
Overton (1954)	Infant mortality		Both	Difference in RR	0.06	2.8
Erickson (1978)	Mortality	All	Both	Adjusted rate-ratio	1.01	3.8
Hagan (1954)	Mortality	Not stated	Both	Adjusted rate-ratio	1.01	3.5
Rogot (1978)	Mortality	Not stated	Both	Difference in RR	0	4.1
Schatz (1976)*	Mortality	Not stated	Both	Difference in RR	-0.1	2.8
	Infant mortality	Not stated	Both	Difference in RR	0.5	
Weaver (1944)	Mortality	Not stated	Both	Difference in RR	0	1.8
Zhao (1996)	IQ	7-14	Both	Mean difference	-7.7	2.5
Lin (1991)	IQ	7-14	Not stated	Mean difference	-6	1.5
	Mental retardation	7-14	Not stated	Crude RR	1.6 (1.15, 2.34)	
Jolly (1971)	Skeletal fluorosis	Not stated	Both	Increased prevalence of skeletal fluorosis at higher fluoride concentrations		2.7
Gedalia (1963)	Goitre	7-18	Female	Crude RR	0.16-1.80	2.5
Jooste (1999)	Goitre	6,12 & 15	Both	Crude RR	0.3-1.2	1.8
Lin (1991)	Goitre	7-14	Not stated	Crude RR	1.11 (1.04, 1.20)	1.5

* Briner (1966) reported data from the same areas and some of the same years but is not presented here because Schatz reported more years and included infant mortality.
** Multiple areas studied, for details on see Appendix C

Six studies looked at the association between Down's syndrome and water fluoride level. Three studies found a negative direction of association (Needleman 1974, Rapaport 1957, Rapaport 1963), one found a positive direction of association, one found no association (Berry 1958) and the other found a positive direction of association for one set of data and a negative direction of association for the other. None of the three studies that found a negative direction of association presented any measure of statistical significance. The one study that found a positive direction of association

(Erickson 1980) did present variance data and failed to find a statistically significant association. The study that found a positive direction of association in one set of data and a negative direction of association in the other did not find a statistically significant association in either direction (Erickson 1976).

10.1 Possible confounding factors

All the studies looking at other possible negative effects used study designs that measured population rather than individual exposures to fluoridated water, and because of this they are susceptible to confounding by exposure. If the populations being studied differed in respect to other factors that are associated with the outcome under investigation, then the outcome may differ between these populations leading to an apparent association with water fluoride level. Which factors may act as confounding factors depends on the outcome under investigation and will thus differ for all the different outcomes discussed above. Nineteen analyses looking at other possible negative effects discussed potential confounding factors (Table 10.2). Twelve of these analyses did not control for any of these confounding factors in the results presented.

Table 10.2 Other possible negative effects associated with water fluoride and the confounding factors controlled for in the analysis.

Author (Year)	Outcome	Confounding factors discussed in study	Controlled for
Forbes (1997)	Alzheimer's disease	Water quality variables	Yes
	Impaired mental functioning		
Still (1980)	Primary degenerative dementia	Chloride, magnesium and calcium content of water	No
Griffith (1963)	Anaemia during Pregnancy	Parity and stage of pregnancy	No
Dick (1999)	Sudden Infant Death Syndrome	Age, region, sex, time, season, gestation, ethnicity, etc	Yes
Erickson (1976)	Down's syndrome	Maternal age, white births only	Yes
Erickson (1980)	Congenital malformations	Maternal age, white births only	No
	Down's syndrome		
Needleman (1974)	Down's syndrome	Maternal age	No
Rapaport (1957)	Down's syndrome	Maternal age	No
Rapaport (1963)	Down's syndrome	Maternal age effect of other minerals in water, iron, magnesium, manganese calcium	No
	Infant mortality		
Overton (1954)	Infant mortality	Ethnicity, social and economic conditions	No
Erickson (1978)	Mortality	Age, sex and ethnicity	Yes
Hagan (1954)	Mortality	Age, sex and ethnicity	Yes
Rogot (1978)	Mortality	Age, sex and ethnicity	Yes
Schatz (1976)	Mortality	Soil and climate	No
	Infant mortality		
Weaver (1944)	Mortality	Age, sex and area compatibility	No
Zhao (1996)	IQ	Educational level of parents	No
Jolly (1971)	Skeletal fluorosis	Sex	Yes
Jooste (1999)	Goitre	Use of iodised salt, height, weight, urinary, water, & salt levels	No
Gedalia (1963)	Goitre	Iodine water level	No

For Down's syndrome, maternal age is of particular importance as a possible confounding factor because the incidence of Down's syndrome is associated with maternal age. This means that if the average maternal age of the fluoridated population is higher than that of the non fluoridated population, an association with water fluoridation would most likely be found. All but one of the six Down's syndrome studies considered the effects of maternal age, however only two of these studies attempted to control for this possible confounding factor. The two studies by Erickson (1976, 1980) included white births only and presented results separately for five-year maternal age groups and one of these studies (1976) presented age-adjusted rates. Both of these studies found a non-significant association of water fluoride level with Down's syndrome at the 5% significance level.

Rapaport (1957) did not control for the effects of confounding factors but did look at the difference in maternal age between the two study areas. He found that maternal age was higher in the low fluoride areas than the high fluoride areas, this would be expected to lead to a higher rate of Down's syndrome in these areas when in fact the reverse was found. Rapaport (1963) also considered maternal age and found that the number of Down's syndrome births to mothers over the age of 40 was greater in the fluoride areas than the low-fluoride areas, however no measures of the significance of this association was presented. Needleman (1974) compared the mean age of mothers in the two study areas and found that maternal age was 34.0 in the high fluoride group and 33.2 in the low fluoride group. The author suggested this was enough to account for the observed differences in the incidence of Down's syndrome found in this study.

Three of the five studies looking at the association between mortality and water fluoridation used standardisation to control for the influence of age, sex and ethnicity (Erickson 1978, Hagan 1954, Rogot 1978). Two of these studies found a negative direction of association; no association was found in the other. None of these studies presented variance data.

Table 10.3 Studies that met inclusion criteria but were not included in the main analysis

Author (Year)	Outcome	Reason	Authors Conclusions
Gupta (1995)	Congenital malformation	No adequate control area - the control area contains <1.5ppm which would be considered a high fluoride area in most studies	There was an increased incidence of spina bifida occulta in children expose to high fluoride (4.5 or 8.5ppm) compared to those expose to low fluoride (<1.5ppm)
Karthikeyan (1996)	Skeletal fluorosis	Areas selected because they were known to have a high incidence of fluorosis and then water fluoride level investigated. Reasons other than the fluoride content of the water are also investigated for the incidence of fluorosis	Skeletal fluorosis was only present in one of the fluorosis regions, the area which had the highest water fluoride content (3.8-8.0)
Latham (1967)	Nail mottling and prevalence of goitre	The results are not broken down as much as the water fluoride levels, giving very wide ranges of fluoride levels in some of the areas for which results are presented. All the areas are fluoridated at above 1ppm and some with fluoride levels as high as 45.5ppm.	Author does not specifically relate results to water fluoride content of the area - he comments generally on the results seen in the whole sample studies, as all areas are exposed to comparatively high levels of fluoride. The percentage of people with mottled nails was high in all areas (>26%) as the prevalence of goitre (12-41%). As these results are not specifically related to the water fluoride level and there was no control area it is difficult to link these findings to the water fluoride levels.
Freni (1994)	Birth rates	The way fluoride exposure is classified` is unclear and misleading; the mean fluoride level in the control areas is sometimes higher than the mean fluoride level in the exposed areas.	A negative association was found between high fluoride levels in drinking water and lower birth rates.
Heasman (1962)	Mortality	The range of water fluoride levels in some of the areas classified as exposed overlaps with the fluoride range in the areas classified as control areas.	The results indicate that the overall mortality was the same in the fluoride and control areas, specific causes of death differences reaching significance at the 5% level. These were conflicting and it was considered very unlikely that fluoride was the cause.
Morgan (1998)	Dental fluorosis and childhood behaviour problems	Children classified according to Dean's classification for fluorosis and then fluoride exposure examined. Childhood behaviour problems classified according to dental fluorosis levels not water fluoride levels	the use of supplemental fluoride prior to age 3 was found to be a risk factor for dental fluorosis. No significant association was found between fluoride history variables in aggregate (including water fluoride level) and dental fluorosis. Dental fluorosis was not significantly associated with behaviour problems in the children studied
Packington (2000)	Fetal, perinatal and infant mortality, congenital malformations and Down's syndrome	Years of data used not the same. No description of methods, unclear exactly how data presented were calculated. Graphs unclear	Fetal, perinatal and infant mortality, congenital malformations and Down's syndrome are higher in fluoridated areas of England than in non-fluoridated areas.
Mitchell (1991)	Sudden Infant Death Syndrome	Data presented graphically. No figures presented in the text. Data could not be read accurately from the graph.	There is no indication of a relationship between fluoridation of the water supply and SIDS in New Zealand.

10.2 Studies that met inclusion criteria but were not included in the main analysis

The eight studies in Table 10.3 were not included in the main analysis of other possible negative effects of water fluoridation for the reasons listed. In three of these studies (Gupta 1995; Freni 1994; Heasman 1962) the control areas included areas that would be considered fluoridated, making interpretation of the results impossible. Data from the other studies were not extracted because of the way the data were presented. Four of these studies conclude that they found a negative relationship with the outcome studied and water fluoridation, two found no association and two did not present clear conclusions.

10.3 Discussion

Interpreting the results of the other possible negative effects is very difficult because of the small number of studies that met inclusion criteria on each specific outcome, the study designs used and the low study quality.

The quality of the research on these topics was generally low, evidence level C (mean of 2.7 out of 8 on validity assessment). Given that all the studies are from lowest the level of evidence with the highest risk of bias, the conclusions should be treated with caution.

A major weakness of these studies generally was the lack of control for any possible confounding factors, many of which were highlighted by the study authors. If the populations being studied differed in respect to other factors that are associated with the outcome under investigation then the outcome may differ between these populations leading to an apparent association with water fluoride level. What is clear is that any further research in these areas needs to be of a much higher quality and should address and use appropriate methods to control for confounding factors.

Overall, the studies examining other possible negative effects provide insufficient evidence on any particular outcome to reach conclusions.

11. OBJECTIVE 5

Are there differences in the effects of natural and artificial water fluoridation?

In order to investigate whether there are differences in the effects of artificially and naturally fluoridated water on positive (caries) and negative (e.g. cancer) outcomes, each of these outcomes will be considered separately. Unfortunately studies of artificially fluoridated areas rarely report what form of fluoride had been used (e.g. sodium fluoride or silicated fluoride). Consequently, identifying the effects of the various forms of fluoride used in artificial fluoridation schemes separately was not possible.

11.1 Caries studies

Only one study compared a naturally fluoridated area, an artificially fluoridated area and a control area using a before and after study design. This was the Brantford-Sarnia-Stratford study (Brown, 1965) in which Brantford was artificially fluoridated, Stratford was naturally fluoridated and Sarnia was the control area. The proportion of caries-free children and the DMFT was measured at baseline (3 years after fluoridation was introduced in Brantford) and then again seven years later, in children aged 9-11 and 12-14 years. Table 11.1 shows the results of this study.

Table 11.1 Caries experience in naturally, artificially and non-fluoridated areas.

Age	Outcome	Brantford (artificial F)		Stratford (natural F)		Sarnia (control)	
		Baseline	Final	Baseline	Final	Baseline	Final
9-11	% caries-free	5.7	43.8	52.1	49.9	6.1	8.1
12-14	% caries-free	1.2	18.7	27.2	28.1	0.6	2.3
9-11	DMFT	4.1	1.5	1.1	1.2	4.2	3.7
12-14	DMFT	7.7	3.2	2.6	2.3	7.9	7.5

At the baseline survey, caries experience, as measured by the proportion of caries-free children and the DMFT score in both age groups, was relatively high in the control area and the area that had recently started to receive fluoridated water. In the survey conducted seven years later, caries experience remained high in the control area and low in the naturally fluoridated area. In the artificially fluoridated area, decay had declined to levels approaching those seen in the naturally fluoridated area. This suggests that naturally and artificially fluoridated water have similar effects on dental decay.

11.2 Possible negative effect studies

11.2.1 Dental fluorosis

A total of 88 studies investigating the association of dental fluorosis and water fluoridation were identified. Of these, 14 did not state whether the water was artificially or naturally fluoridated, 20 compared an area artificially fluoridated (0.6-1.2ppm) with areas of low (<0.3ppm) or very high (4-7ppm) natural fluoride content. The remaining studies only considered naturally fluoridated areas. There were no studies in which an area with water naturally fluoridated to around 1ppm was compared with an area artificially fluoridated to this level. It was therefore not possible to make a direct comparison of the difference in the effect of the naturally fluoridated water compared with artificially fluoridated water.

A term for type of fluoridation (artificial or natural) was included in the regression analysis. This variable did not show an association with fluorosis incidence, suggesting that there is no difference in the effects of artificially and naturally fluoridated water on the incidence of dental fluorosis.

11.2.2 Bone fracture and bone development problems

A total of 29 studies were identified which looked at fracture incidence. Nine compared areas naturally fluoridated at 1ppm with areas of a low natural fluoride level. Eight studies compared areas with different levels of naturally occurring fluoride in the water. Five studies compared areas with mixed (artificial and natural) water fluoride exposure (for example, considering the number of years or proportion of the population exposed to fluoridated water). Seven studies did not state whether the water was artificially or naturally fluoridated. There were no studies in which an area with water naturally fluoridated to around 1ppm was compared with an area artificially fluoridated to this level. It was therefore not possible to make a direct comparison of the effects of naturally fluoridated compared with artificially fluoridated water.

11.2.3 Cancer studies

A total of 26 studies looking at the association of cancer incidence with water fluoridation were found. Twelve studies compared areas with artificially fluoridated water with areas with a low natural fluoride content. Three compared areas with different natural water fluoride levels; one compared areas with mixed (both artificially and naturally fluoridated) water fluoridation; and eight studies did not state whether the water was artificially or naturally fluoridated. There were no studies in which an area with natural fluoride levels around 1ppm was compared with an area artificially fluoridated at this level. It was therefore not possible to make a direct comparison of the difference in effects of naturally fluoridated compared with artificially fluoridated water.

Table 11.2 shows the direction of the association of the water fluoride level with osteosarcoma or bone, joint and overall cancer incidence and mortality for each of these studies, and whether the study compares areas with artificial, natural or mixed water supplies.

There were only two studies that considered areas containing only naturally fluoridated water and so it is difficult to draw conclusions from these results. However, the data suggest that there is no statistically significant association between water fluoridation and cancer incidence, irrespective of whether the fluoridated area is artificially or naturally fluoridated.

Table 11.2 Association of cancer incidence and mortality with water fluoride level by method of fluoridation (artificial, natural, not stated)

Artificially or Naturally fluoridated	Author (Year)	Cancer	Statistically significant association
Artificial	Chilvers (1983)	All cause	No
Artificial	Cook-Mozaffari (1981)	All cause	Not stated
Artificial	Smith (1980)	All cause	Yes (positive effect)
Artificial	Goodall (1980)	All cause	Not stated
Artificial	Richards (1979)	All cause	No
Artificial	Schlesinger (1956)	All cause	Not stated
Artificial	Raman (1977)	All cause	Not stated
Artificial	Mahoney (1991)	Bone	Not stated
Artificial	Hoover (1991)	Bone and joint	No
		Osteosarcoma	No
Artificial	Hrudey (1990)	Osteosarcoma	No
Artificial	Mahoney (1991)	Osteosarcoma	No
Natural	Chilvers (1985)	All cause	No
Natural	Hoover (1976)	All cause	No
		Bone	No
Other	Lynch(1985)	All cause	Yes (negative effect) in 2 of 6 analyses
Other	Kinlen (1975)	Bone	No
Other	Gelberg (1995)	Osteosarcoma	No
Other	McGuire (1991)	Osteosarcoma	No
Other	Moss (1995)	Osteosarcoma	No

11.2.4 Other possible negative effects studies

A total of 31 studies were included in the main analysis assessing the association of other possible adverse effects of water fluoride concentration. Of these, five studies compared areas artificially fluoridated to the 1ppm level with areas with a low natural fluoride level, 11 studies compared areas with different levels of naturally occurring water fluoride levels, and 13 studies did not state whether the areas were artificially or naturally fluoridated. There were two studies in which an area with water naturally fluoridated at around 1ppm was compared with an area artificially fluoridated to this level (Schatz 1976, Rogot 1978). Both studies looked at mortality using a before-after study design, with the baseline survey carried out before water fluoridation was introduced into one of the three study areas. If water fluoride level had a statistically significant effect on mortality, then at the baseline examination mortality would be expected to be higher in the naturally fluoridated area than in the two other, low fluoride study areas. At the final survey, after fluoridation had been artificially introduced into one of these areas, the mortality rate in the artificially fluoridated area would be expected to show an increase in mortality rate to a level approaching (or surpassing) that seen in the naturally fluoridated area. Neither of these studies showed such an association, and neither study showed a statistically significant difference in mortality rates between the study areas. These data have thus not found any association.

A wide range of outcomes was considered with many outcomes only discussed in one or two studies. There is thus insufficient evidence for any of these outcomes to compare the effects of artificially and naturally fluoridated water.

11.3 Discussion

The assessment of natural versus artificial water fluoridation effects is greatly limited due to the lack of studies making this comparison. Very few studies included both areas with low natural fluoride and areas with high natural or artificial fluoride in their studies. In addressing the question of Objective Five for caries studies there was only one study that could be included. The validity assessment (4.5) of this evidence level B study was slightly below the average (5.0) for the caries studies overall. This study was done in Canada and did not control for potential confounding factors in the analysis. The confidence with which the question can be answered by a single study of moderate validity is low.

The ability to address the question of Objective Five with respect to the effect of natural versus artificial fluoridation on negative effects is also low, as there were no direct comparisons of artificial versus natural water fluoride presented.

As the measure of effect estimates reported in all of the bone fracture studies were similar, no difference in the effect based on artificial or natural fluoridation was expected.

There were not enough studies on cancer incidence and mortality reporting the use of only a natural source of fluoride to adequately compare to those reporting only artificial sources (Table 11.2). There were also no studies using mixed (artificial/natural) water supplies that stratified on this basis. From the data presented, no differences are apparent.

For other potential adverse effects, it was not possible to determine the effects of natural versus artificial sources of water fluoridation. In addition to the overall low quality of studies, there were not enough studies on any particular outcome with subjects exposed to different sources of water fluoride to make adequate comparisons.

12. CONCLUSIONS

The conclusions of this systematic review of water fluoridation are as follows:

12.1 Objective 1: What are the effects of fluoridation of drinking water supplies on the incidence of caries?

The best available evidence (level B) from studies on the initiation and discontinuation of water fluoridation suggests that fluoridation does reduce caries prevalence, both as measured by the proportion of children who are caries-free and by the mean dmft/DMFT score. The degree to which caries is reduced, however, is not clear from the data available. The range of the mean difference in the proportion (%) of caries-free children is -5.0 to 64%, with a median of 14.6% (interquartile range 5.05, 22.1%). The range of mean change in dmft/DMFT score was from 0.5 to 4.4, median 2.25 teeth (interquartile range 1.28, 3.63 teeth). It is estimated that a median of six people need to receive fluoridated water for one extra person to be caries-free (interquartile range of study NNTs 4, 9). The best available evidence on stopping water fluoridation indicates that when fluoridation is discontinued caries prevalence appears to increase in the area that had been fluoridated compared with the control area. Interpreting from this data the degree to which water fluoridation works to reduce caries is more difficult. The studies included for Objective 1 were of moderate quality (level B), and limited quantity.

12.2 Objective 2: If fluoridation is shown to have beneficial effects, what is the effect over and above that offered by the use of alternative interventions and strategies?

An effect of water fluoridation was still evident in studies completed after 1974 in spite of the assumed exposure to fluoride from other sources by the populations studied. The meta-regression conducted for Objective 1 confirmed this finding. The studies included for Objective 2 were also of moderate quality (level B), but of limited quantity.

12.3 Objective 3: Does fluoridation result in a reduction of caries across social groups and between geographical locations?

The available evidence on social class effects of water fluoridation in reducing caries appears to suggest a benefit in reducing the differences in severity of tooth decay (as measured by dmft/DMFT) between classes among five and 12 year-old children. No effect on the overall measure of proportion of caries-free children was detected. However, the quality of the evidence is low (level C), and based on a small number of studies. The association between water fluoridation, caries and social class needs further clarification.

12.4 Objective 4: Does fluoridation have negative effects?

The possible negative effects of water fluoridation were examined as broadly as possible. The effects on dental fluorosis are the clearest. There is a dose-response relationship between water fluoride level and the prevalence of fluorosis. Fluorosis appears to occur frequently (predicted 48%, 95% CI 40 to 57) at fluoride levels typically used in artificial fluoridation schemes (1 ppm). The proportion of fluorosis that is aesthetically concerning is lower (predicted 12.5%, 95% CI 7.0 to 21.5). Although 88 studies of fluorosis were included, they were of low quality (level C). The best available evidence on the association of water fluoridation and bone fractures (27 of 29 studies evidence level C) show no association. Similarly, the best available evidence on the association of water fluoridation and cancers (21 of 26 studies evidence level C) show no association. The miscellaneous other adverse effects studied did not provide enough good quality evidence on any particular outcome to reach conclusions. The outcomes related to infant mortality, congenital defects and IQ indicate a need for further high quality research, using appropriate analytical methods to control for confounding factors. While fluorosis can occur within a few years of exposure during tooth development, other potential adverse effects may require long-term exposure to occur. It is possible that this long-term exposure has not been captured by these studies.

12.5 Objective 5: Are there differential effects of natural and artificial fluoridation?

The evidence on natural versus artificial fluoride sources was extremely limited, and direct comparisons were not possible for most outcomes. While no major differences were apparent in this review, the evidence is not adequate to reach a conclusion regarding this objective.

12.6 Limitations of this systematic review

In conducting a large systematic review that extends back to the late 1930's, limitations are inevitable. The primary limitation of the review is the quality of the research included.

The first limitations revolve around the search strategies. More non-English language databases (particularly Russian and Chinese) could have been searched. The impact of failing to search such databases is unknown and the logistic and financial impact of trying to do so would be significant. Some reports were difficult to obtain. However, out of over 730 articles, only 14 were not retrieved. Attempts were made to contact authors to assist in locating further reports, but due to the age of the research were not successful. Additional difficulties were encountered in obtaining some theses and dissertations. Given the comprehensive nature of the search, the completeness of retrieval, and the openness of the review process to the public, the review team feels that it is unlikely that a key study of sufficient size and quality to change any of the findings was missed.

Even comprehensive searches such as that used here may result in a biased collection of studies. Since studies showing a statistically significant result are more likely to be published, the set of published studies located may represent a biased sample and over-estimate an effect (positive or negative).

The validity assessment of the included studies (Appendix D) used a checklist scoring system. This approach can be criticised for lack of sensitivity, in that studies are assessed for having done the items on the list, but not necessarily how well they were conducted. For example, a study could receive points for controlling for confounding factors, but the analysis may not have been performed correctly.

The lack of variance data in some studies, particularly for Objectives 1 and 2, limited the amount of data that could be included in the analyses. Insufficient data prevented statistical pooling of data on social class effects, cancer, other adverse effects, and natural versus artificial fluoride effects. Generally, low to moderate study qualities limit the strength of the possible inferences that can be made.

Some of the studies included in the meta-regression analyses contribute more than one observation to the meta-analysis. It has been assumed in the meta-regression analyses that these observations are independent, and hence each estimate has been treated as though it came from a separate study. For example for studies that report results stratified by age but present no summary measure, results for all strata are included separately in the analysis. However, this approach may introduce bias in the results. Any confounding factors not controlled for, or bias in the study design is likely to be similar for all estimates coming from the same study. Including these estimates as separate estimates in the regression analyses could have the effect of compounding these sources of bias. Study level variables, such as study length and validity score, will also be the same for all the estimates that come from a single study. The direction or degree of any effect of this potential bias is unknown.

12.7 Other factors to be considered

The scope of this review is not broad enough to answer independently the question 'should fluoridation be undertaken on a broad scale in the UK'? Important considerations outside the bounds of this review include the cost-effectiveness of a fluoridation program, total fluoride exposure from environmental and non-environmental sources other than water, environmental and ecological effects of artificial fluoridation and the ethical and legal debates. This review did not include animal or laboratory studies because studies on humans were available and would give more reliable estimates of any potential benefits and harms.

12.7.1 Economic analysis

If a benefit of water fluoridation on caries occurrence was demonstrated, the cost-effectiveness of such an intervention relative to other strategies would need to be carefully considered. The search strategies used in this review did not specifically identify research related to the cost-effectiveness of water fluoridation. A search of the NHS Economic Evaluation Database did not identify any recent studies meeting the criteria for a full economic evaluation.

This review is presenting new information on the effectiveness of water fluoridation in preventing caries and the effects on fluorosis, which previous economic analyses would not have had.

12.7.2 Total fluoride exposure

There is some suggestion that total fluoride exposure has increased over recent years, particularly in industrialised nations. Exposure to fluoride from sources other than water may alter the amount required in water for optimum caries reduction and is thus a potential confounding factor in studies of the association between water fluoridation and negative effects. Because sources of fluoride exposure vary, this may be a difficult issue to examine, in that exposure would need to be measured at the person level, rather than at the population level. However, if two study areas are comparable, in all respects, the fluoride exposure from non-water sources (e.g. tea) should also be similar. There are studies that have measured total fluoride exposure in people exposed to fluoridated and non-fluoridated water, but these did not meet inclusion criteria for this review (Guha-Chowdhury, 1996, Mansfield, 1999). Because of potential toxicity of very high doses of fluoride, it would seem sensible that any future studies should attempt to measure total fluoride exposure in areas being researched.

12.8 Information to guide practice

The available evidence shows that water fluoridation reduces the prevalence of caries. The median difference between fluoridated and non-fluoridated areas in the proportion of children who are caries-free is 14.6%, while the reduction in the number of teeth affected (dmft/DMFT score) is 2.3. The available evidence shows that fluorosis occurs in approximately 48% of the population at water fluoridation levels of 1.0ppm. The proportion who have teeth that are affected enough to cause aesthetic concern is approximately 12.5%. The quality of these data on benefit and harm is in general only low to moderate, and should be interpreted with caution, especially considering the significant heterogeneity between studies. The benefit and harm data need to be considered in conjunction when making decisions about water fluoridation.

12.9 Implications for research

Although there has been considerable research in this area, the quality is generally low. The research needs that have been identified through this systematic review are described below.

12.9.1 Caries studies

The two most important factors missing from the current set of studies are adjusting for confounding factors using standard analytic techniques, and reporting variance data. In addition to the potential confounding factors noted in section 4.2.2, frequency of sugar consumption, measurement of total exposure to all sources of fluoride, the number of erupted teeth per child, and the level of spending on dental health in intervention and control areas should be included. Blinding of observers should be attempted and at least standardisation of the assessment would be essential to reduce the potential impact of observer bias. Studies should also consider changes in social class structure over time. Only one included study addressed the positive effects of fluoridation in the adult population. Assessment of the long-term benefits of water fluoridation is needed.

It would be logical to include an assessment of adverse effects alongside any future study of caries. While fluorosis may be evident in young populations within a few years of starting fluoridation, other potential adverse effects may take longer to occur, or may occur largely in an adult population.

Most of the evidence on social class effects of fluoridation was from cross-sectional studies of low quality. If further studies are considered, social class effects could be incorporated into a study of fluoridation efficacy. More research into the most appropriate tool to measure social class in relation to dental health is also needed.

12.9.2 Adverse effects studies

The results of this review suggest that a dose-response relationship exists between water fluoride level and the prevalence of fluorosis. Future studies should address the impact of using lower levels of water fluoride content, such as 0.8ppm in a formal way in conjunction with an efficacy study. The potential confounding factors and causes of between study heterogeneity identified in this review should be controlled for in the analysis.

With bone fracture and cancer studies, the evidence is very balanced around the ‘no effect’ mark. If any further research is considered, controlling for confounding factors and ensuring adequate blinding should be a priority.

The other possible adverse effect studies suffered greatly by not sufficiently controlling for important confounding factors, many of which were discussed by authors in the study reports, but not controlled for. Very few of the possible adverse effects studied appeared to show a possible effect. High quality research that takes confounding factors into account is needed.

12.9.3 Economic evaluations

When evaluating the cost-effectiveness of an intervention such as water fluoridation, there are key factors to be considered. The costs of the intervention are weighed against the benefits. A full economic evaluation of water fluoridation should include a complete accounting of the potential costs of the intervention (cost of fluoridating, administration costs, and quality assurance costs) and the benefits. Examples of the benefits that should be included are the reduction in caries that is assumed, any changes in the number of dental visits, procedures, and long-term effects such as changes in the need for dentures. The quality of life (QOL) of those who receive the intervention should be measured, in comparison to those not receiving the intervention (such as the effect of not losing teeth to caries, the effect of having fluorosed teeth, anxiety associated with dental visits, and dental pain). Indirect costs of travel time and time off work for parents to take children to the dentists could also be included. Such an economic evaluation could be done along side an intervention study measuring actual resource use and costs, or as a modelling exercise using the most accurate efficacy data (e.g. from this systematic review). Differences in dental resource use among social classes should also be investigated.

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