

The dental benefits of water fluoridation

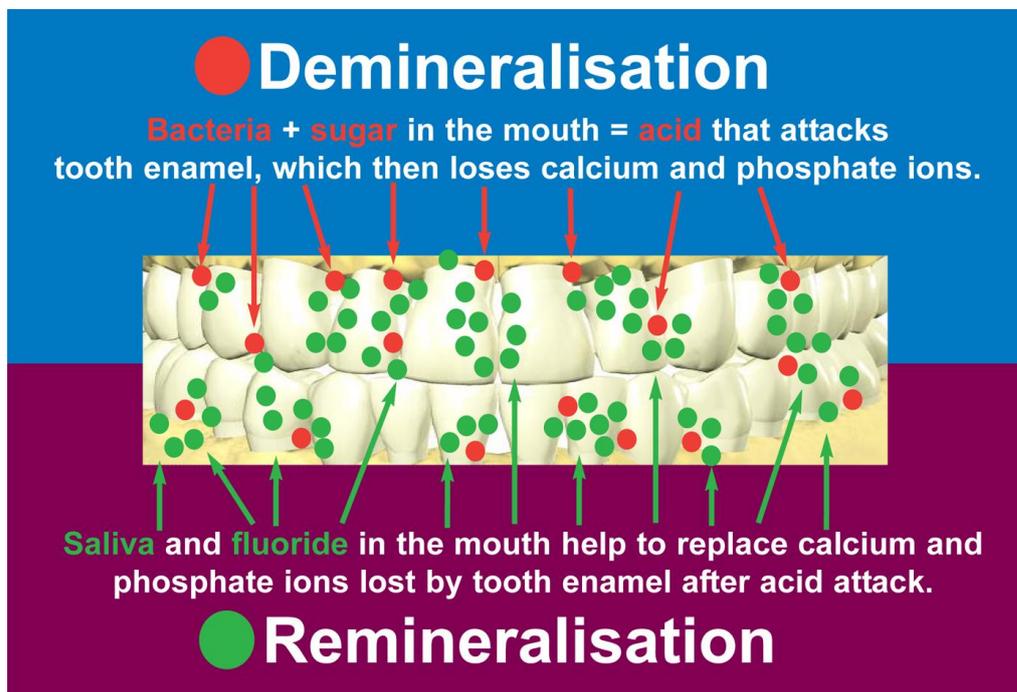
KEY POINTS

- Fluoridation of water supplies reduces the number of decayed, missing and filled teeth in children and adults.
- As a result of fluoridation, children experience less toothache, have fewer dental abscesses and require fewer dental extractions and general anaesthetics.
- The cost to the NHS of treating avoidable disease is therefore reduced.
- While tooth decay levels have fallen in both fluoridated and non-fluoridated communities in recent years, inequalities in dental health remain wide.
- There is still a strong case for extending fluoridation on a targeted basis in those parts of the UK with persistently high tooth decay levels among children, particularly in the North of England, Scotland, Wales, Northern Ireland and inner London.

1. How fluoride works to prevent tooth decay

Tooth decay begins when the enamel – the outer surface of the tooth – is destroyed by acid. The acid is produced by bacteria, which form on the surfaces of the teeth as a layer called plaque. When foods or drinks containing sugars enter the mouth, the bacteria within the plaque rapidly convert the sugars into acid. The plaque can hold the acid in contact with the tooth surface for up to two hours before it is neutralised by saliva.

Demineralisation and remineralisation of tooth enamel – the ‘ionic see-saw’



During the time when the plaque is acidic, some of the calcium and phosphate minerals of which enamel is largely composed are dissolved out of the enamel into the plaque. This process is called demineralisation. However, once the plaque acid has been neutralised, the minerals can return into the enamel – a process called remineralisation. This movement between demineralisation and remineralisation is often described as an ‘ionic see-saw’ in which mineral ions constantly move back and forth between the tooth enamel and plaque (1).

The capacity for remineralisation is, however, limited. If sugars enter the mouth too frequently, the net loss of mineral from the enamel surface will result in a cavity, through which bacteria can penetrate and infect the inner structure of the tooth. This is tooth decay. If left untreated, it will gradually destroy the tooth, causing pain and leading to the formation of a dental abscess.

The three ways in which fluoride makes a difference

The relationship between fluoride and tooth decay is complex and probably not yet fully understood. However, it is known that fluoride modifies the process of tooth decay in at least three ways:

If children take in sufficient fluoride during the period when tooth enamel is developing, the fluoride improves the chemical structure of the enamel, making it more resistant to acid attack. Theoretically, this can occur from the first stage of tooth enamel mineralisation while a foetus is in the womb until the last teeth erupt in the mouth, which for wisdom teeth could be at about 20 years of age.

These **systemic effects of fluoride** were originally thought to be the most important mechanism by which fluoride benefits teeth. However, with advances in scientific knowledge this is now generally understood to be of lesser importance than the topical effects of fluoride on teeth after they have erupted.

When teeth are subjected to alternating demineralisation and remineralisation, as explained above, the presence of low levels of fluoride in the plaque and saliva both encourages remineralisation and ensures that the enamel crystals that are laid down are of improved quality. In other words, low levels of fluoride in the mouth gradually improve the strength of the tooth enamel and its ability to resist acid attack.

This important mechanism, first described in 1966, means that early patches of tooth decay can be arrested and that damaged enamel will 'heal'. These **topical effects of fluoride** help to explain the dramatic improvement in dental health since the introduction of fluoride into toothpaste formulations in the mid-1970s.

The third possible way in which fluoride works is by **reducing the ability of the plaque bacteria to produce acid**. It results from the ability of the plaque bacteria to concentrate low levels of fluoride at the tooth surface up to a level that inhibits the function of enzymes that are essential to the bacteria's production of acid.

Topical effect is significant

Work to further develop scientific knowledge of the mechanism of fluoride continues. Nevertheless, on the basis of what is already known it is possible to say that the topical effect of fluoride in aiding the remineralisation process is significant (2).

The goal of maintaining low levels of fluoride in everybody's mouth for as long as possible is therefore critical - hence the importance of water fluoridation and the regular use of fluoride toothpaste. Together, they represent a powerful combination against tooth decay.

2. The extent to which water fluoridation benefits dental health

All water supplies contain fluoride naturally. Early studies of tooth decay in the United States established that a naturally occurring concentration of 1 part of fluoride per million parts of water (1 ppm) was associated with significantly lower levels of tooth decay (3).

In most places in the UK, the natural fluoride level in water is too low to be of benefit to dental health. However, it is possible by a process known as fluoridation to 'top up' the fluoride that is naturally present in water in order to reproduce the dental benefits that natural fluoridation at or around 1 ppm brings.

The world's first water fluoridation scheme was introduced in the United States in 1945 to serve the community of Grand Rapids, Michigan. The first 'demonstration' schemes in the UK followed in the mid-1950s and, over the past 50 years, many more schemes have been implemented in countries around the world.

The impact of fluoridation on tooth decay has been closely observed during that period, with many studies having compared the levels of tooth decay in both fluoridated and non-fluoridated communities.

University of York estimates of dental benefits for 5 to 15 year olds

Between 2000 and 2013, four systematic reviews of the available scientific evidence on the benefits of water fluoridation have been published. The first was undertaken by the Centre for Reviews and Dissemination at the University of York, whose research team looked at 26 previously conducted studies to see whether a trend could be identified (4). The York team found that:

- Water fluoridation reduces the number of decayed, missing and filled teeth in children aged 5 to 15 by, on average, 2.25 teeth per child. This works out at an overall reduction in tooth decay of approximately 40% in fluoridated areas (5).
- Water fluoridation increases the percentage of children totally free from tooth decay by, on average, 14.6%.
- The reduction in the number of decayed, missing and filled teeth following fluoridation is greatest in those areas where children had the highest levels of tooth decay at the outset.

On a population-wide basis, these benefits are very significant. However, the average reductions identified by York cannot be assumed to apply to all children of all ages in all fluoridated areas. These estimates were obtained from studies of children of different ages in different countries at different times. The estimates also relied on data aggregated from studies of tooth decay in children's primary teeth and permanent teeth.

In practice, therefore, some children may experience a greater reduction in tooth decay than the York figures suggest. Others, by contrast, may experience a lower reduction. As the York review found, however, the greater the average level of tooth decay among children before a fluoridation scheme starts, the greater the average reduction in tooth decay it is likely to achieve.

One of the team responsible for the York report, Jos Kleijnen, was later co-author of a paper describing the five steps to conducting a systematic review. Having selected the University of York's systematic review of water fluoridation as a case study, Kleijnen and his co-authors examined the issues that, in their opinion, public health professionals in localities with a water fluoridation scheme need to consider in assessing its effects on people's health (6). They concluded: "On the issue of the beneficial effect of water fluoridation, the review (i.e., the York review) reassures you that the health authority was correct in judging that fluoridation of drinking water prevents caries."

US Task Force estimates of dental benefits for 4 to 17 year olds

In 2002, a US Task Force on Community Preventive Services published the findings of its systematic review of 21 studies that had explored the benefits of water fluoridation (7). One analysis of the effects of starting water fluoridation found an average tooth decay reduction of 50.7% among children aged 4 to 17 during 3 to 12 years of follow up. Other analyses of different types of study found reductions varying from an average of 29.1% to 41.2%.

The US Task Force concluded: "Community water fluoridation reduces dental caries by 30%–50% of what could be expected for people not consuming fluoridated water...The results of the review should apply to most populations in the United States and other industrialised countries." The Task Force went on to recommend water fluoridation on the basis of what it described as 'strong evidence of effectiveness in reducing tooth decay' (7) (8).

Australian National Health and Medical Research Council systematic review of the evidence

A further systematic review, published by the Australian National Health and Medical Research Council (NHMRC) in 2007, examined the methods and conclusions of the earlier York and US Task Force reviews, as well as relevant studies conducted since York. The NHMRC concluded that the introduction of fluoridation was 'strongly associated' with a reduction in levels of decayed, missing and filled teeth and with an increase in the percentage of caries-free children (9).

US systematic review of the benefits for adults (Griffin et al)

In 2007, a US research team led by Dr Susan Griffiths from the Centers for Disease Control and Prevention completed a systematic review of previously conducted studies that had explored the effectiveness of water fluoridation in preventing tooth decay in adults (10).

After analysing data from seven studies, they calculated that adults who had lived all their lives in fluoridated communities had, on average, 34.7% fewer teeth decayed, missing and filled than those who had lived all their lives in non-fluoridated communities.

A further analysis of five studies completed after 1979 found that, on average, the number of decayed, missing and filled teeth was reduced by 27.2% among adults who had been lifelong residents in fluoridated areas.

Tooth loss in adults related to fluoride level in water at birth

More recently, a study by US researchers has shown that the fluoride level in water at the time of a person's birth is significantly related to tooth loss in adulthood and that the beneficial impact of fluoridated water is greater in individuals of lower socio-economic status (11).

Predictive tool for estimating benefits from future fluoridation schemes

Foster et al have provided a tool for predicting the potential improvements in children's dental health that could be achieved from introducing fluoridation in particular parts of the UK (12). In developing the tool, they used data from the NHS national programme of dental epidemiological surveys of over 150,000 five-year old children and 100,000 eleven-year old children in 2004/05.

The average levels of tooth decay for each Primary Care Trust (PCT) were plotted against the Index of Multiple Deprivation (IMD) for that PCT and its fluoridation status. Overall, fluoridation was found to reduce the number of decayed, missing and filled teeth in 5-year olds by 46% and in 11-year olds by 33%. The tool developed from this formula enables an estimate to be

calculated for an expected benefit from future fluoridation schemes based on the deprivation status of specific PCTs.

3. Why fluoridate water when people can use toothpaste?

Since fluoride toothpaste became the norm in the UK (from the mid-1970s), tooth decay rates have fallen in both fluoridated and non-fluoridated communities. The key question, therefore, is whether children living in fluoridated communities still have better teeth.

Evidence suggesting additional benefits from water fluoridation

To answer this question, the York review focused on studies conducted since 1974 when widespread use of fluoride toothpaste can be assumed. In examining these post-1974 studies, the York team concluded that the dental benefits of water fluoridation were over and above those of fluoride toothpaste and other sources of fluoride.

Furthermore, a Cochrane collaboration review of 74 studies of the effectiveness of fluoride toothpaste also concluded that water fluoridation had a benefit over and above that of fluoride toothpaste (13).

4. Does water fluoridation reduce inequalities in dental health?

How children from more affluent backgrounds have benefited most from the introduction of fluoride toothpaste

Improvements in dental health over the past 30 or so years (mainly due to the introduction of fluoride in toothpaste) have not been evenly distributed across all social groups. Because more well-informed and affluent parents are the most likely to restrict their children's sugar intake and ensure that they brush their teeth twice daily with a fluoride toothpaste, children from these environments have benefited more than those from poorer backgrounds (14).

The social divide and severe tooth decay

Severe tooth decay remains a problem among young children in disadvantaged communities. For example, according to a survey of 5-year olds' dental health across England in 2007/08, more than half of children (51.4%) in this age group living in Manchester have some tooth decay (15).

On average, Manchester children with experience of tooth decay have nearly five teeth (4.63) decayed, missing and filled, of which at least one tooth will

have been extracted. Tooth extraction in such young children is generally performed under a general anaesthetic.

Clearly, a reduction in the number of tooth extractions among Manchester children – and among those from other communities with persistently high levels of tooth decay – would bring significant benefits to their health and well-being, as well as allowing better use to be made of scarce NHS resources.

Evidence that fluoridation reduces differences in dental health between social groups

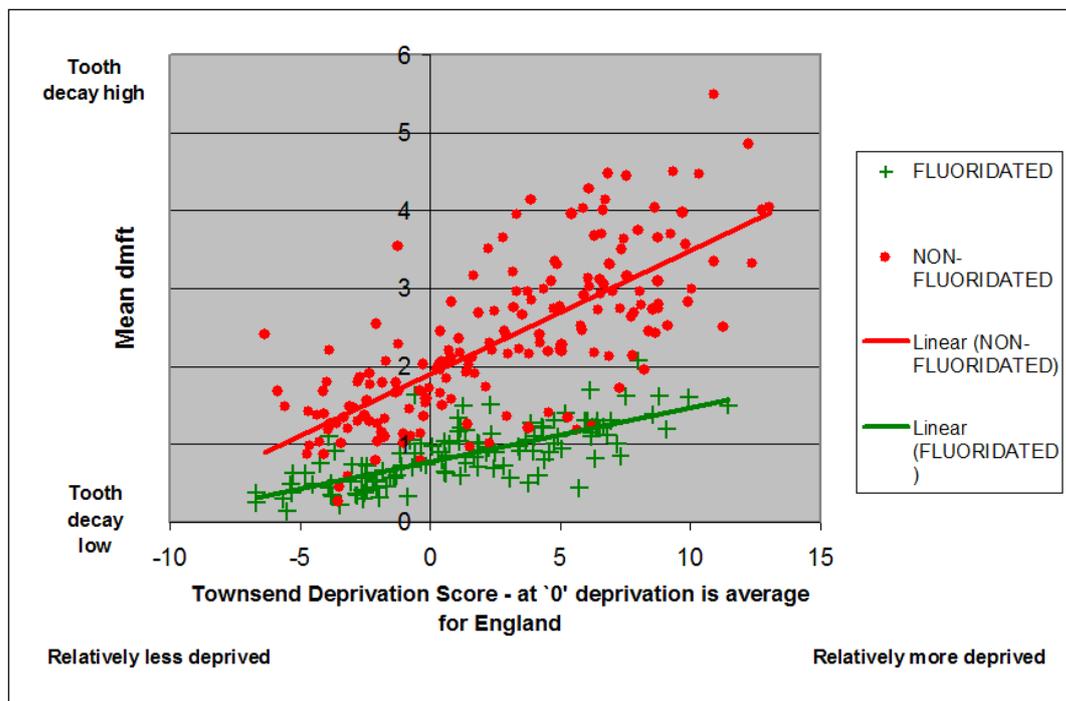
So the question arises as to whether or not water fluoridation reduces dental health inequalities in any way? Do poorer children who drink fluoridated water have less tooth decay than poorer children in non-fluoridated areas? This is an important issue for those who are responsible for public health. The York review team specifically looked at previous studies that had attempted to measure the effects of fluoridation on children from different social groups.

The small number of studies conducted in this field and the relatively low quality rating given by the York reviewers to those studies suggest a need for caution in interpreting their findings. Nevertheless, the York review found that, in terms of the average number of decayed, missing and filled teeth, “...there appears to be some evidence that water fluoridation reduces the inequalities in dental health across social classes in 5 and 12-year olds”.

A study that correlates social deprivation, tooth decay rates and fluoridation status

One important study included in the York review looked at the dental health of 5-year olds living in electoral wards of seven fluoridated areas and seven matched non-fluoridated areas with varying degrees of social deprivation (16). The study concluded that water fluoridation reduces tooth decay more in disadvantaged communities than in affluent communities, and that the introduction of water fluoridation schemes in areas where levels of poverty and tooth decay are high, such as Manchester, “would substantially reduce inequalities in dental health”.

Figure 1:



Graph reproduced from Riley et al, by permission of Oxford University Press.

Figure 1 shows the relationship between tooth decay and social deprivation in both fluoridated and non-fluoridated communities. It demonstrates that:

- Young children (5-year olds) living in poverty generally have higher levels of tooth decay than more affluent children.
- Water fluoridation reduces the effects of social deprivation on tooth decay.
- The difference in tooth decay rates between poor and affluent children is smaller in fluoridated communities than in non-fluoridated communities.
- Where the level of deprivation is the same, children in non-fluoridated communities have more tooth decay than those in fluoridated communities.
- When two communities with national average levels of social deprivation are compared, children from the non-fluoridated one have an average of just over one additional tooth decayed compared with children from the fluoridated one.
- When two communities with 10% more than the national average level of social deprivation are compared, children from the non-fluoridated one have around two more decayed teeth than children from the fluoridated one. In other words, the link between poverty and tooth decay is weaker in fluoridated areas than non-fluoridated areas.

How to interpret Figure 1

The position of each community shown on the chart below is determined by two factors:

1. The average number of decayed, missing and filled teeth (mean dmft) per 5-year old child (see vertical axis).
2. The level of social deprivation in the community as measured by its Townsend score (see horizontal axis) (17).

Green crosses mark the positions of fluoridated communities. Red dots mark the positions of non-fluoridated communities.

The average Townsend score for England is 0. A very socially deprived community would have a score of +10 or more (over on the right hand side of the chart). A relatively affluent community would have a score of less than 0. So a score of, say, -5 over on the left hand side of the chart, indicates low levels of social deprivation.

What does the graph tell us about the relationship between water fluoridation, tooth decay and social deprivation? Both lines slope upwards. This tells us that young children living in poverty have higher levels of tooth decay than more affluent children. However, the red line (non-fluoridated communities) is steeper than the green line (fluoridated communities), which tells us that fluoridation is reducing the effects of deprivation on tooth decay.

In addition, we can see that the red (non-fluoridated) line is always higher up the chart than the green (fluoridated) line. This tells us that where the level of deprivation is the same, children in non-fluoridated communities have more tooth decay than those in fluoridated communities. The difference in tooth decay rates increases as the level of deprivation increases.

Pooling of UK studies

The York review looked at a number of UK studies investigating the relationship between tooth decay, social deprivation and water fluoridation (including the study described above in figure 1). Five of the studies focusing on the dental health of 5-year olds used the same classification of social class (18, 19, 20, 21, 22). The York review team was therefore able to combine these results (see figure 2).

Figure 2: Tooth decay in 5-year old children by social class and water fluoridation – average number of decayed, missing and filled teeth per child (dmft)

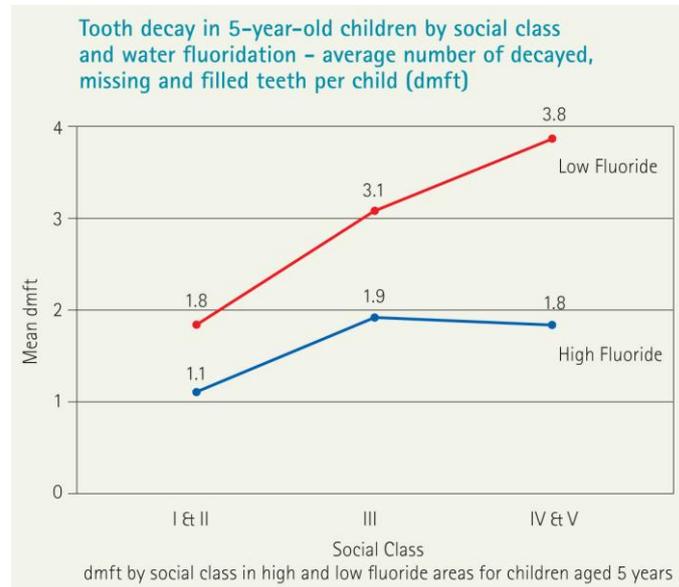


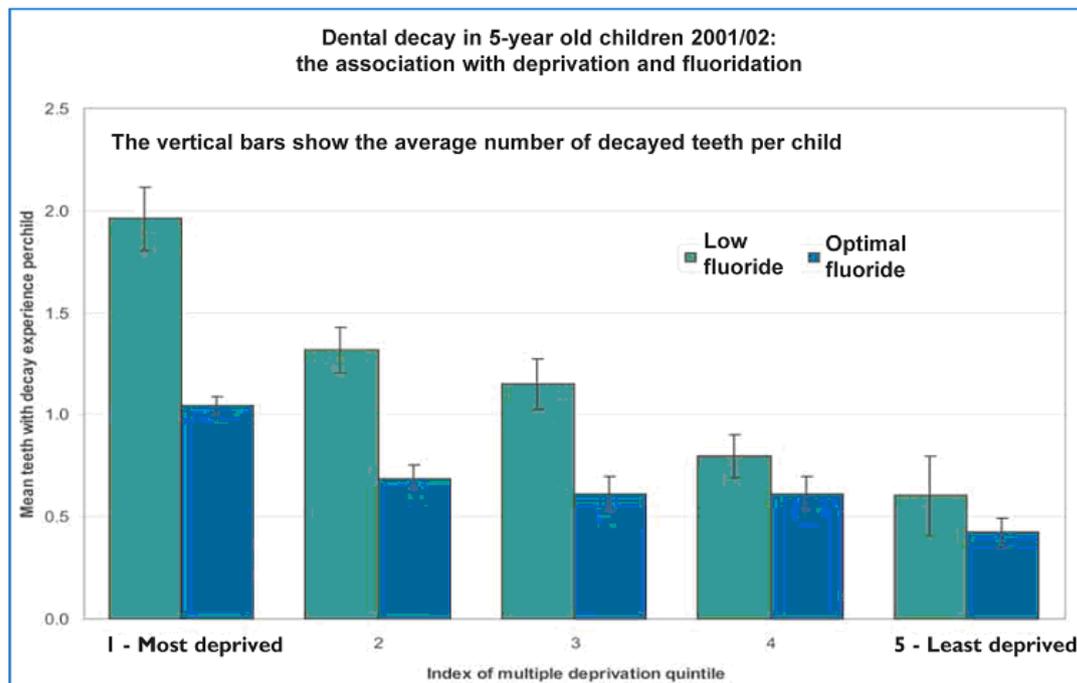
Figure 2 shows that, across all social classes, the number of teeth affected by decay is lower in the fluoridated than the non-fluoridated communities. Importantly, the teeth of 5-year old children in the lowest social classes (IV and V) in the fluoridated communities are as healthy as those of children in the highest social classes (I and II) in the non-fluoridated communities. Again, this demonstrates that water fluoridation can modify the usual link between poverty and severe tooth decay.

Analysis of West Midlands data on social deprivation, tooth decay rates and fluoridation status

In 2006, an analysis of tooth decay rates across the West Midlands published in a report by the regional director of public health (23) showed that:

- Children in fluoridated areas with relatively high levels of social deprivation often had better dental health than children in relatively affluent areas where water supplies are not fluoridated (see figure 3).
- In fluoridated areas there was a smaller difference in tooth decay rates between children in the most affluent and most socially deprived families than there was between children from these different social groups in non-fluoridated areas (see figure 3).

Figure 3:



Comparing the West Midlands with other regions

From the 2010 health profiles of English regions and areas produced by the Association of Public Health Observatories (APHO) it is possible to compare the West Midlands with the rest of the country in terms of relative deprivation and children's dental health (24).

The West Midlands is one of the most deprived regions in the country. Nearly five times more people in the West Midlands than the South East (27.4% compared with 5.9%) are among the most deprived fifth of the population of England. Levels of deprivation across the West Midlands are significantly worse than the national average.

Despite its relatively high social deprivation, the West Midlands has significantly better children's dental health than other regions with comparable deprivation. On average, 5-year olds in the North West region and Yorkshire and The Humber region have 50% more tooth decay than those in the West Midlands, whilst 5-year olds in London have 30% more tooth decay than those in the West Midlands.

The West Midlands has the most extensively fluoridated water supplies of any region in the country. Around 70% of its residents receive fluoridated tap water in their own homes, compared with just 4% in the North West and less than 3% in Yorkshire and The Humber.

Five-year olds in the West Midlands have the same level of dental health overall as children from the entirely non-fluoridated South West, although

around three times more people from the West Midlands are among the most deprived fifth of the England population. This is further evidence of the benefits of water fluoridation in reducing the effects of deprivation.

5. Medical Research Council review of the York report

In 2000, the Department of Health asked the Medical Research Council (MRC) to set up a working group to assess the findings of the York review of water fluoridation and make recommendations on any further research that might be required (25). The MRC working group took full account of York's analysis of previously conducted studies on the efficacy of fluoridated water in reducing tooth decay. It also looked at several relevant, mainly UK-based studies that had not been included in the York review.

Looking beyond the fluoridation outcome measures considered by York

The MRC working group noted that, in considering the effects of water fluoridation on tooth decay, the York review had looked only at those studies presenting baseline and follow up data for both fluoridated and non-fluoridated communities, and that outcome measures were limited to the prevalence of tooth decay and average levels of decayed, missing and filled teeth. Further, the MRC group noted that York had not included studies of outcome measures such as:

- the percentage of children with high levels of decayed, missing and filled teeth;
- the number of extracted teeth;
- experience of general anaesthesia for dental extraction;
- toothache;
- the prevalence of dental abscesses;
- the long term dental effects in communities with naturally fluoridated water; and
- 'cross sectional' studies that examine and compare levels of tooth decay in communities at a particular moment in time.

The MRC group therefore broadened the scope of its review beyond the narrower range of studies included in the York analysis. From this additional work, the group highlighted other studies suggesting that fluoridation:

- reduces the amount of toothache suffered by children, and thereby improves the quality of their lives;
- reduces the need for dental treatment involving general anaesthesia;
- reduces tooth decay in children as young as 3 years old and in adults aged up to 75;

- has an important post-eruptive, topical effect on teeth, which means it can potentially benefit older children and adults as well as individuals born after fluoridation starts;
- benefits people living in non-fluoridated areas who consume foods and drinks made with fluoridated water, which may narrow what would otherwise be a wider gap in dental health between fluoridated and non-fluoridated communities.

6. Fluoridation benefits indicated by other studies

Improved dental health and quality of life for all age groups, from the very young to older adults

The results of a range of studies demonstrating the benefits of water fluoridation are given in tables 1 to 12.

Table 1: Children aged 3 (teeth affected by decay)

Reference	Year of Survey	Fluoridated Community	dmft	Non-Fluoridated Community	dmft	Difference in dmft	% Difference in dmft
[26]	1989	Huddersfield	0.30	Dewsbury	0.74	0.44	59%

This study compared numbers of decayed, missing and filled teeth in 3-year olds in two Yorkshire communities (26). Those from (then) fluoridated Huddersfield had, on average, 59% fewer teeth affected than those from non-fluoridated Dewsbury.

Table 2: Children aged 5 (teeth affected by decay)

Reference	Year of Survey	Fluoridated Community	dmft	Non-Fluoridated Community	dmft	Difference in dmft	% Difference in dmft
[27]	1981	Newcastle	1.4	Northumberland	3.4	2.0	59%
[28]	1985	Newcastle	1.3	N. Manchester	3.3	2.0	61%
[29]	1987	Newcastle	1.8	Northumberland	3.9	2.1	54%
[30]	1987	Anglesey	0.8	Gwynedd (Mainland)	2.3	1.5	65%

This table shows the results of four studies carried out in the 1980s to compare numbers of decayed, missing and filled teeth in 5-year olds (27, 28, 29, 30). Those from the fluoridated communities (Newcastle and Anglesey) had, on average, between 54% and 65% fewer teeth affected than those from the non-fluoridated communities (Northumberland, North Manchester and mainland Gwynedd).

Table 3: Children aged 14 and 15 (teeth affected by decay)

Reference	Year of Survey	Fluoridated Community	dmft	Non-Fluoridated Community	dmft	Difference in dmft	% Difference in dmft
[31]	1987	Birmingham	2.3	Bolton	3.8	1.5	40%

This study compared numbers of decayed, missing and filled teeth in 14 to 15 year old children (31). Those from fluoridated Birmingham had 40% fewer teeth affected than those from non-fluoridated Bolton.

Tables 4 and 5: Children aged 5, 14 and 15 (% free from tooth decay)

Reference	Year of Survey	Fluoridated Community	Proportion (%) of children who are caries free	Non-Fluoridated Community	Proportion (%) of children who are caries free	Difference in proportion (%) of children who are caries free
[27]	1981	Newcastle	55	Northumberland	31	24
[28]	1985	Newcastle	62	N. Manchester	29	33
[29]	1987	Newcastle	50	Northumberland	32	18
[30]	1987	Anglesey	67	Gwynedd (Mainland)	48	19

Reference	Year of Survey	Fluoridated Community	Proportion (%) of children who are caries free	Non-Fluoridated Community	Proportion (%) of children who are caries free	Difference in proportion (%) of children who are caries free
[31]	1987	Birmingham	32	Bolton	19	13

These tables show percentages of children completely free from tooth decay. On average, there were between 13% and 33% more children free from tooth decay in the fluoridated communities than in the non-fluoridated communities.

Table 6: Benefits for children aged 12 when fluoridation started

Reference	Year of Survey	Fluoridated Community	DMFT Increment over a 4-year period	Non-Fluoridated Community	DMFT Increment over a 4-year period	Difference in DMFT Increment	% Difference in DMFT Increment
(32)	1974/9	Alsager, Middlewich and Nantwich	3.76	Northwich	4.85	1.09	22.4%

This study examined the effect of fluoridation on 12-year olds (32). It was included in the York review as the highest quality study, and there are three important features we would like to highlight:

- The study focuses on the post-eruptive (or topical) effects of water fluoridation;
- The study followed the same children over time; and,

- By bussing the children to a common examination site, the clinical examiner was unaware of whether the child lived a fluoridated or non-fluoridated area.

Over the four years immediately after fluoridation started in Alsager, Middlewich and Nantwich, the study tracked the dental health of children who had been 12 years old at the time, comparing them with others of the same age in non-fluoridated Northwich. As table 6 shows, in that period the children from the three fluoridated communities experienced an average of 22% fewer decayed, missing and filled teeth than those from non-fluoridated Northwich

Table 7: Benefits for adults in terms of natural teeth retained throughout life

Reference	Year of Survey	Fluoridated Community	Non-Fluoridated Community	Age of subjects	Findings
[33]	1968/9	Hartlepool	York	15 - 65 years	Fluoridation reduced caries experience, tooth mortality, and the need for partial dentures in all 5-year age bands between 15 and 65 years.
[34]	1979 - 1989	Review, several studies included			In adults, including older adults, fluoridation reduced caries by between 15 and 35%.
[35]	Early 1980s	Iowa 8 communities naturally fluoridated 3 communities artificially fluoridated	Iowa 6 non-fluoridated communities	Average age: 75.2 Fluoridated 74.1 Fluoridated	Significant benefits resulted for those with 30 - 40 years of exposure to fluoridated water which suggested that fluoridation was beneficial even though exposure started in adulthood.
[36]	1989/90	Ireland Communities fluoridated since mid-1960s	Ireland Communities never fluoridated	16 - 65+ years	In fluoridated areas the percentage of adults with no natural teeth was lower- e.g. in 45-54 year olds only 10.8% in fluoridated communities compared with 29.5% in non-fluoridated, had no natural teeth. In fluoridated communities adults had more natural teeth - e.g. in 45-54 year olds had 16.4 natural teeth in fluoridated communities compared with only 10.7 in non-fluoridated - a 34% difference.
[37]	1986/1987	Anglesey	Gwynedd mainland	Antenatal patients up to 32 years	Lifelong residents of fluoridated Anglesey had on average 30% fewer decayed, missing or filled teeth.

The studies presented in table 7 demonstrate that adults living in fluoridated communities keep more of their own teeth longer and have much less trouble with them than adults in non-fluoridated communities.

For example, a 1989/90 study in the Irish Republic found that only 10.8% of 45 to 54 year olds in fluoridated communities had no natural teeth, compared with 29.5% in non-fluoridated communities. The same study also found that, overall, adults in this age group living in non-fluoridated communities had 34% fewer natural teeth remaining than their counterparts in fluoridated communities.

Another study conducted in Wales in 1986/87 found that up to the age of 32 lifelong residents of (then) fluoridated Anglesey had, on average, 30% fewer decayed, missing and filled teeth than those in non-fluoridated mainland Gwynedd.

Professor Robin Heath, former director of dental care for the elderly at the Royal London Hospital, has commented on what he sees as the benefits of

water fluoridation for older people. He said: “Fluoridation of drinking water provides a safe, cheap and practical method of reducing dental disease, and reducing the consequent pain and severe problems that can result from tooth loss in old age.”

Tables 8, 9 and 10: Children aged 5 (risk of having toothache, tooth extractions and needing a general anaesthetic)

Reference	Year of Survey	Fluoridated Community	% Prevalence	Non-Fluoridated Community	% Prevalence	Difference in % Prevalence
[27]	1981	Newcastle	12%	Northumberland	27%	15%
[28]	1985	Newcastle	9%	N. Manchester	24%	15%
[29]	1987	Newcastle	18%	Northumberland	27%	9%
[30]	1987	Anglesey	5%	Gwynedd (mainland)	13%	8%

Reference	Year of Survey	Fluoridated Community	% Prevalence	Non-Fluoridated Community	% Prevalence	Difference in % Prevalence
[27]	1981	Newcastle	8%	Northumberland	23%	15%
[28]	1985	Newcastle	6%	N. Manchester	18%	12%
[29]	1987	Newcastle	8%	Northumberland	18%	10%
[30]	1987	Anglesey	6%	Gwynedd (mainland)	9%	3%

Reference	Year of Survey	Fluoridated Community	% Prevalence	Non-Fluoridated Community	% Prevalence	Difference in % Prevalence
[27]	1981	Newcastle	7%	Northumberland	21%	14%
[28]	1985	Newcastle	7%	N. Manchester	12%	5%
[29]	1987	Newcastle	9%	Northumberland	17%	8%
[30]	1987	Anglesey	5%	Gwynedd (mainland)	8%	3%

These tables show the results of four studies that compared 5-year old children’s experience of toothache, tooth extractions and having teeth extracted under a general anaesthetic. Overall, the studies found that:

- children in non-fluoridated communities were generally between about one and a half and three times more likely than those in fluoridated communities to have suffered toothache;
- children in non-fluoridated communities were between about one and a half and three times more likely than those in fluoridated communities to have had decayed teeth extracted;
- children in non-fluoridated communities were between about one and a half and three times more likely than those in fluoridated communities to have had a general anaesthetic for dental extractions.

Table 11: Children aged 5 (prevalence of dental abscesses)

Reference	Year of Survey	Fluoridated Community	% Prevalence	Non-Fluoridated Community	% Prevalence	Difference in % Prevalence
[27]	1987	Newcastle	1%	Northumberland	5%	4%

The study presented in this table shows that 5-year olds in non-fluoridated Northumberland were five times more likely to suffer dental abscesses than those in fluoridated Newcastle.

Table 12: Children aged 5 (prevalence of severe tooth decay)

Reference	Year of Survey	Fluoridated Community	% Prevalence	Non-Fluoridated Community	% Prevalence	Difference in % Prevalence
*[28]	1985	Newcastle	1%	N. Manchester	10%	9%
[29]	1987	Newcastle	16%	Northumberland	31%	15%
[30]	1987	Anglesey	4%	Gwynedd (mainland)	20%	16%

* In this study high caries was defined as 10 or more teeth affected.

This table shows the results of three studies focusing on particularly high levels of decay. Two of the studies found that children in non-fluoridated communities were between two and five times more likely than those in fluoridated communities to have experienced *severe* tooth decay (five or more teeth decayed per child). One study found that children in non-fluoridated North Manchester were ten times more likely than those in fluoridated Newcastle to have had 10 or more teeth affected by decay.

Use of NHS resources and costs of dental treatment

A number of studies have compared the cost of dental treatment needed by children in fluoridated and non-fluoridated communities. Costs have usually been calculated according to the pre-2006 NHS General Dental Service fee scale, which is based on the average time taken to complete specific items of treatment. Table 13 shows that 5-year old children in non-fluoridated communities have been found to need treatment costing 61% more than that needed by children in fluoridated communities.

Reference	Year of survey	Year of fee scale	Fluoridated community	Cost	Non-fluoridated community	Cost	% Difference
[29]	1987	1986	Newcastle	£5.00	Northumberland	£12.75	61%

Clearly, new water fluoridation schemes in areas of high need would free up scarce NHS resources (both financial and human) to be used to meet other health care needs (see Section of One in a Million on Costs and Cost-effectiveness).

Other key points

Other key points to note from the additional studies reviewed by the Medical Research Council are:

- In all of the studies of children, those from fluoridated communities had better dental health, with fewer teeth affected by decay.

- A greater proportion of children in fluoridated areas had no tooth decay at all.
- On average, fluoridation saved around 2 teeth per child from decay – similar to the difference reported by York.
- Children in fluoridated communities had between 42% and 65% fewer decayed, missing and filled teeth than those in similar, non-fluoridated communities.

It is reasonable to conclude that, if introduced in those parts of the UK with the worst children's dental health – such as the North West of England, Yorkshire, the West of Scotland, Northern Ireland and Inner London – water fluoridation could significantly improve dental health and well-being for all, but particularly children and adolescents living in the least affluent communities.

7. Some post-York studies of the dental benefits

Study of 11-13 year olds in fluoridated Newcastle and non-fluoridated Manchester

A study published in 2012 compared the tooth decay experience of children aged 11 to 13 with similar social backgrounds, sugar consumption patterns and oral hygiene practices in fluoridated Newcastle upon Tyne and non-fluoridated Manchester (38).

The study relied on two different methods - clinical examination and digital photography - to identify tooth decay in both sets of children. Researchers using photographs of teeth to score levels of decay were unaware which city the children came from. Both methods were used to assess and record signs of all levels of decay - from white spot lesions to more advanced decay into the dentine of the tooth.

When all levels of tooth decay were compared, clinical examinations found that children from fluoridated Newcastle had, on average, 34% fewer decayed, missing and filled teeth than those from non-fluoridated Manchester. Photographic evidence suggested the difference was around 27%.

When only more advanced decay (into dentine) was compared, clinical examinations found that children from fluoridated Newcastle had, on average, 39% fewer decayed, missing and filled teeth than those from non-fluoridated Manchester. Photographic evidence suggested a difference of 41%.

Comparisons of 'decay-free' children

Around 67% of Newcastle children, compared with 54% of those from Manchester, were free of more advanced decay (into dentine), whilst 25% of children in Newcastle were free of all forms of decay, including early white spot lesions, compared with 15% in Manchester.

The study found that, on average, 11-13-year olds in five social groups in Newcastle (from the most affluent to the least affluent) had fewer teeth affected by early or advanced decay than those from the equivalent group in Manchester. However, the difference between children from the most affluent groups in the two cities was not statistically significant.

The difference in the number of decayed teeth between children from the most and least affluent groups in Manchester was greater than the difference between children from the most and least affluent groups in Newcastle. More children in each of the five social groups in Newcastle were decay-free than in the equivalent group from Manchester.

Table 14: Average number of decayed, missing and filled teeth among children aged 11 to 13 (all forms of decay from early white spot lesions to more advanced decay into dentine)

Clinical examination results

Reference	Year of Survey	Fluoridated Community	DMFT	Non-fluoridated Community	DMFT
	2008/09	Newcastle upon Tyne	2.94	Manchester	4.48

Photograph assessment results

Reference	Year of Survey	Fluoridated Community	DMFT	Non-fluoridated Community	DMFT
	2008/09	Newcastle upon Tyne	2.51	Manchester	3.44

Table 15: Average number of decayed, missing and filled teeth among children aged 11 to 13 (more advanced decay into dentine)

Clinical examination results

Reference	Year of Survey	Fluoridated Community	DMFT	Non-fluoridated Community	DMFT
	2008/09	Newcastle upon Tyne	0.65	Manchester	1.07

Photograph assessment results

Reference	Year of Survey	Fluoridated Community	DMFT	Non-fluoridated Community	DMFT
	2008/09	Newcastle upon Tyne	0.58	Manchester	0.98

Table 16: Percentage of 11 to 13 year olds free of all forms of decay (from early white spot lesions to more advanced decay into dentine)

Reference	Year of Survey	Fluoridated Community	% who are caries free	Non-fluoridated Community	% who are caries free
	2008/09	Newcastle upon Tyne	25%	Manchester	15%

Table 17: Percentage of 11 to 13 year olds free of more advanced decay into dentine

Reference	Year of Survey	Fluoridated Community	% who are caries free	Non-fluoridated Community	% who are caries free
	2008/09	Newcastle upon Tyne	67%	Manchester	54%

New Zealand oral health survey identifies benefits for children and adults

A 2008-09 oral health survey in New Zealand, comprising dental examinations of around 3,200 New Zealanders aged 2 and over as well as just under 5,000 interviews, found that children and adults in fluoridated parts of the country had less tooth decay than those in non-fluoridated areas (39).

Children aged between 2 and 17 years old in non-fluoridated areas were found to have an average of 2.4 decayed, missing and filled teeth, compared with those in fluoridated areas who had, on average, 1.5 teeth affected.

Adults aged 18 and over in non-fluoridated areas had, on average, 15.7 decayed, missing and filled teeth, compared with 12.2 in fluoridated areas.

The authors of the study say that although this analysis is only a snapshot, the findings indicate overall that adults and children who lived in fluoridated areas of New Zealand had lower experience of dental caries than those without a fluoridated water supply. This difference exists, they say, despite the fact that the majority of people in both fluoridated and non-fluoridated areas brush their teeth with a fluoride toothpaste.

The authors stress that the migration of people into and out of areas with fluoridated water means that the true protective effect of water fluoridation may have been under-estimated in the study.

These latest statistics from New Zealand reinforce the findings of other surveys and studies. For example, a 2004 study by Lee and Dennison found that 5-year olds in non-fluoridated Canterbury had 58% more tooth surfaces decayed, missing and filled than children of the same age in fluoridated Wellington.

Table 18: New Zealand oral health survey, 2008/09. Average number of decayed, missing and filled teeth among children aged 2 to 17

dmf/DMFT	
Non-fluoridated communities:	2.4
Fluoridated communities:	1.5

Table 19: New Zealand oral health survey, 2008/09. Average number of decayed, missing and filled teeth among adults aged 18 and over

DMFT	
Non-fluoridated communities:	1.57
Fluoridated communities:	1.22

Table 20: New Zealand oral health survey, 2008/09. Average number of decayed, missing and filled teeth among children and adults combined

dmf/DMFT	
Non-fluoridated communities:	1.21
Fluoridated communities:	0.96

Australian study of adults

An Australian study published in March 2013 showed reductions in tooth decay of between 11% and 30% for adults who had lived all or a large part of their lives in fluoridated areas (40).

Researchers from the Universities of Adelaide and North Carolina reviewed the dental health of over 3,700 participants in the national survey of adult oral health conducted in Australia between 2004 and 2006, together with residential histories since 1964 and their toothbrushing habits and use of fluoride supplements.

Some of the adults in the study had started to drink fluoridated water when they were born or during early childhood. Others grew up in non--fluoridated areas but had spent some of their adult years in fluoridated areas. Some had never benefited from fluoridation. Individuals' experience varied significantly.

After the residential histories of study participants had been matched with the fluoride levels in community water supplies where they had lived, researchers

were able to determine what percentage of their lives had been spent in places with artificial fluoridation schemes in operation.

Analysis of all the data showed that, on average, adults born before 1960 with prolonged exposure to fluoridated water during their lives had 12% fewer decayed, missing and filled teeth than those from the same age group with negligible exposure. The difference was 11% among adults born between 1960 and 1990.

The differences were greater when decayed and filled tooth surfaces were compared. Adults born before 1960 with prolonged exposure to fluoridated water during their lives had, on average, 30% fewer decayed and filled surfaces than those with negligible exposure. The difference was 21% among adults born between 1960 and 1990.

The researchers conclude that, based on this representative sample of Australian adults, greater lifetime exposure to water fluoridation is associated with lower levels of caries experience.

Analysis of post-1990 fluoridation studies

An analysis of 59 studies published in the scientific literature between 1990 and 2010 found that, on average, fluoridation reduces tooth decay in primary teeth by between 30% and 59% and in permanent teeth by between 40% and 49% (41). Each study had compared levels of tooth decay in fluoridated and non-fluoridated communities.

Between them the studies examined the effects of fluoridation on teeth in ten different countries – the United States, Canada, Argentina, Brazil, the United Kingdom, Ireland, Israel, South Korea, Australia and New Zealand. The age groups of the people included in those studies ranged from 3 to 44.

According to the analysts, one marked change in the way fluoridation studies have been carried out since 1990 is the use of advanced statistical techniques to adjust for potentially confounding factors. When this latest analysis looked at studies in which such confounding factors had been taken into account, it found that there was hardly any effect on the scale of reductions in children's tooth decay achieved by fluoridation.

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