Further Studies in Caries and Fluorosis

A thesis submitted to the University of Manchester

for the degree of Doctor of Philosophy in the Faculty of Medicine and Human Sciences

2011

Michael Gerard McGrady

School of Dentistry

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

ANOVA	analysis of variance
$Area_{blur}$	area of tooth considered fluorosis (existing/blur technique)
$Area_{ch}$	fraction of tooth area considered fluorosis (convex hull technique)
BASCD	British Association for the Study of Community Dentistry
CCD	Charge-coupled device
CI	Confidence Intervals
CWS	cooking water sample
DDE	Developmental Defects of Enamel (Index)
df	degrees of freedom
DHU	Dental Health Unit
DMFT/S	Decayed Missing Filled Teeth/Surfaces
$D_{1\text{-}6}$MFT	DMFT from ICDAS codes threshold at white spot lesion
$D_{4\text{-}6}$MFT	DMFT from ICDAS codes threshold at caries into dentine
DWS	drinking water sample
DoH	Department of Health
ICDAS	International Caries Detection and Assessment System
ECM	Electronic caries monitor
EDJ	enamel dentinal junction
EPA	Environmental Protection Agency
FRI	Fluorosis Risk Index
FN	False negative
FOTI/diFOTI	Fibre Optic Transillumination /Digital Imaging FOTI
FP	False positive
ICC	Intra-class correlation co-efficients
ICOH	Intercountry Centre for Oral Health
IMD	Index of Multiple Deprivation
LED	Light Emitting Diode

MCL	maximum contaminant level
MCLG	maximum contaminant level goal
mg F/L	milligrams fluoride per litre
MRC	Medical Research Council
NHS	National Health Service
NRC	National Research Council
OR	Odds Ratio
OHRQoL	Oral Health Related Quality of Life
ppm	parts per million
QLF	Quantitative light-induced fluorescence
RGB	Red, green, blue
RI	Refractive Index
SD/±	Standard deviation
SE	Standard Error
SMCL	secondary maximum contaminant level
SPSS	Statistical Package for Social Sciences
VidRep	Video repositioning
TF	Thylstrup and Fejerskov (Index)
TSIF	Tooth Surface Index of Fluorosis
ΔF_{blur}	fraction fluorescence loss compared to sound enamel (existing/blur technique)
ΔF_{ch}	average fluorescence loss of areas considered fluorosis (convex hull technique)
ΔQ_{blur}	fraction fluorescence loss integrated by lesion area in mm^2
ΔQ_{ch}	average fluorescence loss over entire tooth surface

The University of Manchester

ABSTRACT of the thesis submitted by Michael Gerard McGrady for the Degree of Doctor of Philosophy entitled Further Studies in Caries and Fluorosis.

The main drivers for this body of work were a systematic review on water fluoridation by the NHS Centre for Research Dissemination (known as the York Report) and a report by the Medical Research Council entitled “Water Fluoridation & Health”. Both documents highlighted shortcomings in the evidence base on water fluoridation. Two major projects form the basis of this thesis in an attempt to address some of the issues raised.

The first project in Chiang Mai, Thailand aimed to determine the ability of QLF to discriminate between populations with differing exposures to fluoride. Populations with differing exposures to fluoride were identified through the analysis of drinking water and cooking water. Subjects were examined for fluorosis with standardized photographs and QLF to evaluate software techniques for fluorescence image analysis. The results in Thailand demonstrated that QLF was able to discriminate between populations with differing exposures to fluoride in water to a similar degree to blinded, subjective clinical scoring. There was significant agreement between the two methods (ICC 0.65 Spearman’s rho). However, confounding factors for QLF were found.

The aim of the second project was to assess the use of blinded and objective methods for assessing caries and fluorosis in fluoridated Newcastle and non-fluoridated Manchester in northern England. This study involved clinical and intra-oral photographic caries examinations using ICDAS, together with standardized photography and QLF imaging for fluorosis examinations. The results in Newcastle and Manchester suggested that there were significantly lower levels of caries in the fluoridated population compared to the non-fluoridated population. For early caries (Newcastle mean DMFT 2.94[clinical]/2.51[photo], Manchester mean DMFT 4.48 [clinical]/3.44[photo]) and caries into dentine (Newcastle Mean DMFT 0.65[clinical]/0.58[photo], Manchester mean DMFT 1.07 [clinical]/0.98 [photo]). This was reflected as an increase in caries as the level of deprivation increased (confirmed through intra-oral photographic scoring). The reduction in caries levels was associated with increased levels of fluorosis in Newcastle. The prevalence of fluorosis from photographic scores in fluoridated Newcastle was 55%, in non-fluoridated Manchester it was 27%. In Newcastle, 48% of subjects had TF scores of 1 or 2 and 7.1% of subjects had TF scores of 3 or greater. QLF showed significant associations with the clinical scores for fluorosis (ICC 0.405 Kendall’s tau) and suggested a fluorosis prevalence for TF 3 or greater of 19% in Newcastle and 10% in Manchester.

The integration of technologies such as intra-oral photographs for blind caries scoring and QLF for the detection and objective quantification of fluorosis may still prove to be useful adjunctive tools when used alongside clinical indices. The data derived from the methodologies under investigation suggest a benefit in caries reduction from community water fluoridation and this may help to reduce inequalities in oral health by reducing the social gradient between deprivation and caries.

August 2011

DECLARATION

No portion of the work referred to in the thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

COPYRIGHT STATEMENT

ACKNOWLEDGMENTS

When I took up post in the University of Manchester/Colgate Palmolive Dental Health Unit in 2007 I was acutely aware of the international reputation the unit had developed. The list of eminent personnel that had passed through the unit left me with a feeling of great pride, a sense of responsibility and a great deal of trepidation.

I have been privileged to have been guided by two highly respected supervisors in Professor Iain Pretty and Professor Roger Ellwood. Roger's knowledge of his subject matter is encyclopaedic and he not only provided a great of support and guidance but was incredibly generous with his time and access to resources – materials, equipment and support staff. The mentoring and support I have received from Iain during my studies cannot be easily summarized in a few words. From an academic perspective he was available to facilitate when required and to encourage when necessary – always with purpose and great humour. From a professional point of view Iain worked hard and selflessly to provide me with opportunities to attend conferences internationally and to progress my career. Most importantly, he has been a tremendous source of support on a personal level, particularly during my daughter's hospitalization and convalescence. Iain has proven to be an example to aspire to and, I hope, a good friend and future collaborator. The result of having two superb, but differing, supervisors meant that on occasions scenarios were dealt with from three separate perspectives. The subsequent dialectic invariably resulted in stronger work with infrequent cross words.

The academic endeavours undertaken in this body of work required the support and efforts of many people. At some point over the last few years every individual in the DHU has generously given their time. Special thanks go to Nicola Boothman who worked tirelessly to co-ordinate the project in Newcastle and Manchester and Michaela Goodwin was invaluable during data preparation and analysis. Without their support and expertise the project would have ground to a halt. Dr Naveen Mohan spent many hours in schools in Newcastle and Manchester taking photographs and QLF images at a time when he had his own doctorate thesis to submit. Paul Hindmarch and Dipesh Patel also provided great support performing photographic and QLF duties. Dr Andrew Taylor provided bespoke computer software for data collection and invaluable (and frequent!) assistance during image analysis. Brenda Bradshaw provided meticulous auditing of the study files. I would also like to thank Johanna Moloney for assisting in the schools in Manchester. Laura Davies spent many hours performing data entry. The statistical advice and support I received from Professor Helen Worthington was invaluable. Her expertise was coupled with patience, which was evident throughout and for which I am eternally grateful.

I am also grateful for the support I received outside of the DHU and the University of Manchester. I would like to thank Associate Professor Patcharawan Srisilapanan and Narumanas Korwanich and all the team at the Faculty of Dentistry, Chiang Mai University, Thailand for their hard work and support on the study we ran in Chiang Mai.

I would like to thank Professor Jimmy Steele and Dr Anne Maguire from the School of Dental Sciences, Newcastle University for their time during protocol development, contract negotiations and steering group meetings during the Newcastle arm of the main study. I am grateful to Dianne Tabari, Clinical Director for Community Dentistry, Newcastle for her time and patience in allowing us access to her staff in order to conduct the study in Newcastle. Deborah Howe and Val Dalton provided invaluable assistance in the Newcastle schools – dealing with school liaison, consent, clinical scribing and file co-ordination.

Finally I would like to thank my mother and the rest of my family. The encouragement and support that they have provided never faltered. Victoria deserves the most gratitude. She fully endorsed my need to go on this “little adventure” and tolerated the stresses and strains that accompanied it all. I was absent for long periods during her pregnancy with Sophia as I travelled both domestically and abroad. Her patience and tolerance to the less attractive aspects of my persona at times were tested to the full and I owe her an immense amount of gratitude, and apologies.

I dedicate this thesis to my daughter Sophia Ellen-Jane McGrady and to the memory of my father Gerard Joseph McGrady (1935-1983).

Further Studies in Caries and Fluorosis

Chapter 1

Introduction

Introduction to Thesis

The format of this thesis follows the University of Manchester alternative thesis format sometimes known as journal format. The literature review is presented over three chapters encompassing a series of published articles covering the use of fluoride in dentistry, water fluoridation and the debate associated with it. Key areas not covered by these articles such as caries detection, fluorosis indices and fluorescent imaging are addressed in the introduction that follows. The main body of the thesis covers two separate projects and iterative processes that were required in order to deliver the objectives of this thesis and are presented as separate chapters.

The project in Thailand was set up following a contact provided by the Borrow Milk Foundation. I was involved in the initial negotiations with Chiang Mai University. I was lead author on the protocol and trained the local staff in TF Index, standardized photograph technique and QLF together with Prof Roger Ellwood. I was responsible for the mask drawing and QLF analysis with guidance from Dr Andrew Taylor and statistical input from Prof Helen Worthington. Consensus TF Index scores were carried out in conjunction with Prof Ellwood. I am lead author on the publications that will result from this work.

For the project in Newcastle and Manchester I was involved with the study design and protocol as well as initial contact with schools together with Nicola Boothman and Debora Howe. During the study I acted as sole clinical examiner and intra-oral photographer. I acted as remote scorer for intra-oral images for caries and TF Index for fluorosis. Data entry, cleaning and analysis was carried out in conjunction with Laura Davies, Nicola Boothman and Michaela Goodwin with guidance from Prof Helen Worthington. I am the lead author on the publications that will arise from this work.

A summary chapter draws together the findings of this work and suggests direction for future work.

Introduction

The relationship between fluoride, dental caries and developmental defects of enamel has been the subject of investigation for over 100 years. The use of fluoride in dentistry in the latter part of the 20th Century led to a dramatic fall in caries incidence through such measures as the fluoridation of community water supplies and the use of fluoridated oral care products. At the same time as the reduction in caries there has been an increase in the prevalence of fluorosis (Brunelle and Carlos 1990; Whelton, Crowley et al. 2004; Whelton, Crowley et al. 2006; Chankanka, Levy et al. 2010).

In September 2000, in the UK, the Department of Health (DoH) published a systematic review on water fluoridation. This report was carried out by the Centre for Reviews and Dissemination, University of York and became known in the dental research community as the York Report (NHS-CRD 2000). The York Report was commissioned by the Chief Medical Officer to *'carry out an up to date expert scientific review of fluoride and health'* (DOH 1999). There were five key objectives of the review:

1. To examine the effects of fluoridation of water on the incidence of caries
2. To examine any effects of water fluoridation (if any) over and above those offered by alternative interventions and strategies
3. To examine if water fluoridation results in caries reduction across social groups and geographical locations, bringing equality
4. To examine if negative effects of water fluoridation exist
5. To examine if there are differences in the effects of natural and artificial water fluoridation

The report concluded that "the evidence of a benefit of a reduction in caries should be considered together with the increased prevalence of dental fluorosis." Despite the fact that current research on fluoridation supported the benefits of water fluoridation; certain aspects within the evidence base were not acceptable and the York Report commented that future research should address these issues. The report recommended that evidence showing a benefit of a reduction in dental caries should also consider the increase in prevalence of dental fluorosis. The report also stated the evidence base did not permit confidence in statements relating to potential harm or the impact on social inequalities. The report also concluded that future research should be "*considered along with the ethical, environmental, ecological, costs and legal issues that surround any decisions about water fluoridation"*.

Following the York report, a Medical Research Council (MRC) publication; Water Fluoridation & Health (MRC 2002) also issued guidance on the research shortfalls in fluoride research and again recommended that this be a priority area for research in the future. The report focused on seeking better information on the differing presentations of fluorosis, the aesthetic impact of fluorosis to the individual and also the appearance of enamel defects where the aetiology is not linked to fluoride.

The MRC also recommended that fluoride exposure in children should be examined to identify the impact of water fluoridation on the reduction in caries against a background of wider fluoride exposure from alternative sources, especially toothpaste. Greater knowledge is needed on how the effects of water fluoridation vary with social class, a link between dental caries prevalence and socio-economic group has been generally accepted (Rugg-Gunn AJ, Carmichael CL et al. 1977; Hinds and Gregory 1995). The majority of the research to date suggests water fluoridation may reduce dental caries inequalities between high and low socio-economic groups (Carmichael CL, Rugg-Gunn AJ et al. 1989). The report recommended that research focused on appropriate measures of social inequalities related to water fluoridation, dental caries and fluorosis, taking into account factors such as use of other fluoridated products such as toothpaste and dietary sugar ingestion.

At a time of high caries prevalence, traditional methods of caries detection (visual-tactile examination and radiography) were deemed to be acceptable with higher levels of specificity compensating for poorer levels of sensitivity (Maupome and Pretty 2004). As caries rates have declined, the pattern of caries has changed with an increased incidence of occlusal caries.

This has resulted in the profession gaining an increased understanding of the caries process and recognition that an improvement in early caries detection was necessary (Pitts 2004; Pretty 2006). Failure to detect early lesions may result in deep enamel or cavitated lesions that respond less well to interventions designed to encourage remineralization. The focus was on early detection and quantification of caries together with an assessment of mineral loss that embraced emerging technologies and diagnostic science thus enabling the use of preventative measures. The assessment of fluorosis has changed little during this period of time with the continued use of subjective clinical indices.

There are inconsistencies in criteria used in the process of caries detection (Chesters, Pitts et al. 2002; Ricketts, Ekstrand et al. 2002; Ismail 2004). Fundamental differences emerged between the United States and Europe. On the whole, the USA used a dichotomous approach of cavitation or no cavitation when assessing dental caries. Whereas in Europe (within the research community), there was an expression of the clinical stages of the caries process that preceded cavitation.

Visual assessment of caries requires subjective and qualitative measures of features of the caries process that, unfortunately, whilst providing valuable information do not provide a true quantification of disease severity and provide limited detection of early lesions. Once it has been established a lesion is present the concept of lesion measurement must be considered. This process must take into account the different histological appearances of lesions of different sizes and type (Featherstone 2004). It is also important that diagnostic cut-offs (thresholds) are established (Pitts and Fyffe 1988). These thresholds are an arbitrary decision point on what would be classified as disease and what would be classified as sound. Pitts (Pitts 1997; Pitts 2001; Pitts and Stamm 2004) described an updated metaphor for diagnostic thresholds known as the caries "iceberg" (Figure 1.1). The iceberg illustrated the range of caries diagnostic thresholds that are used within clinical practice and research. The iceberg arranges lesions of increasing severity in a stack. It is an attempt to compartmentalize what is in fact a continuum of lesion progression. At a certain point in time, a lesion can exist in one particular level or diagnostic threshold. The "water levels" on the iceberg illustrate the different threshold levels for what would constitute diseased or sound teeth. The arrows on the left of the iceberg demonstrate the extent to which caries could be missed in a diagnosis if the D_3 threshold was used without diligence.

The D_3 threshold (caries into dentine) has been used for many years as an epidemiological tool in order to capture data on caries prevalence (Pitts, Evans et al. 1997). Dental caries has also been recorded using variations of the decayed, missing and filled (DMF) index developed in the 1930's by Klein and Parker. The DMF score can be adapted to report scores calculated by teeth (DMFT) or by tooth surface (DMFS). This index has the advantage of being simple and quick and is universally recognized. However, by reporting caries at the D_3 threshold it is not capable of addressing caries at lower levels of severity. The British Association for the Study of Community Dentistry (BASCD) has made attempts to address the limitations of the DMF index (Pitts, Evans et al. 1997). However, the problem still remains in reporting lesions of low severity.

A committee of dental health professional and cariologists have attempted to address the shortcomings in the various caries detection systems employed and the differing diagnostic thresholds each system uses. The International Caries Detection and Assessment System (ICDAS) set out to address four issues:

1) what stage of the caries process should be measured;
2) what are the definitions for each selected stage;
3) what is the best clinical approach to detect each stage on different tooth surfaces; and
4) what protocols of examiners' training can provide the highest degree of examiner reliability?

The aim was to develop a system that can serve as a standard for clinical and epidemiological research and inform dental undergraduate and postgraduate teaching in cariology as well as facilitating caries detection in clinical practice (Pitts 2004; Ismail, Sohn et al. 2007). ICDAS attempts to address the clinical detection of caries lesions toward the base of Pitt's caries "iceberg" (Figure1.1). The scoring system employed attempts to validate a clinical score with the histological stage of the lesion i.e. the level of demineralization of enamel and dentine. The criteria for ICDAS are listed in Appendix 1.

A range of caries detection systems have been developed that use the measurement of physical signals such as electronic current, visible light and laser light to act as surrogate measures of the caries process. Techniques such as subtraction radiography, fibre optic transillumination (FOTI and DiFOTI), intra-oral photography and laser fluorescence have been developed to assist the early detection of caries. The relative benefits and the sensitivity and specificity of such systems have been discussed in the literature (Bader, Shugars et al. 2001).

Subtraction Radiography

A progression from the advent of digital radiography is that of subtraction radiography. The basis of subtraction radiology is that two radiographs of the same object can be compared using their pixel values. If the series of radiographs have been taken using geometry stabilizing apparatus (i.e. a bitewing holder) or computer software has been employed, then changes in the pixel values between the images must be due to change in the object (Wenzel, Pitts et al. 1993). The changes in the images must be attributable to either the onset or progression of demineralization, or regression. Subtraction images therefore can highlight these changes and the sensitivity is increased. It is crucial the alignment of successive images is as reproducible as possible otherwise discrepancies in alignment could result in pixels being incorrectly represented as change (Ricketts, Ekstrand et al. 2007). Advances in software have enabled two images with moderate alignment to be correctly aligned and then subtracted. An example of a subtraction radiograph is shown in Figure 1.2.

Figure 1.1. Pitts' "iceberg of dental caries"—diagnostic thresholds in clinical trials and practice (From Pitts 2004).

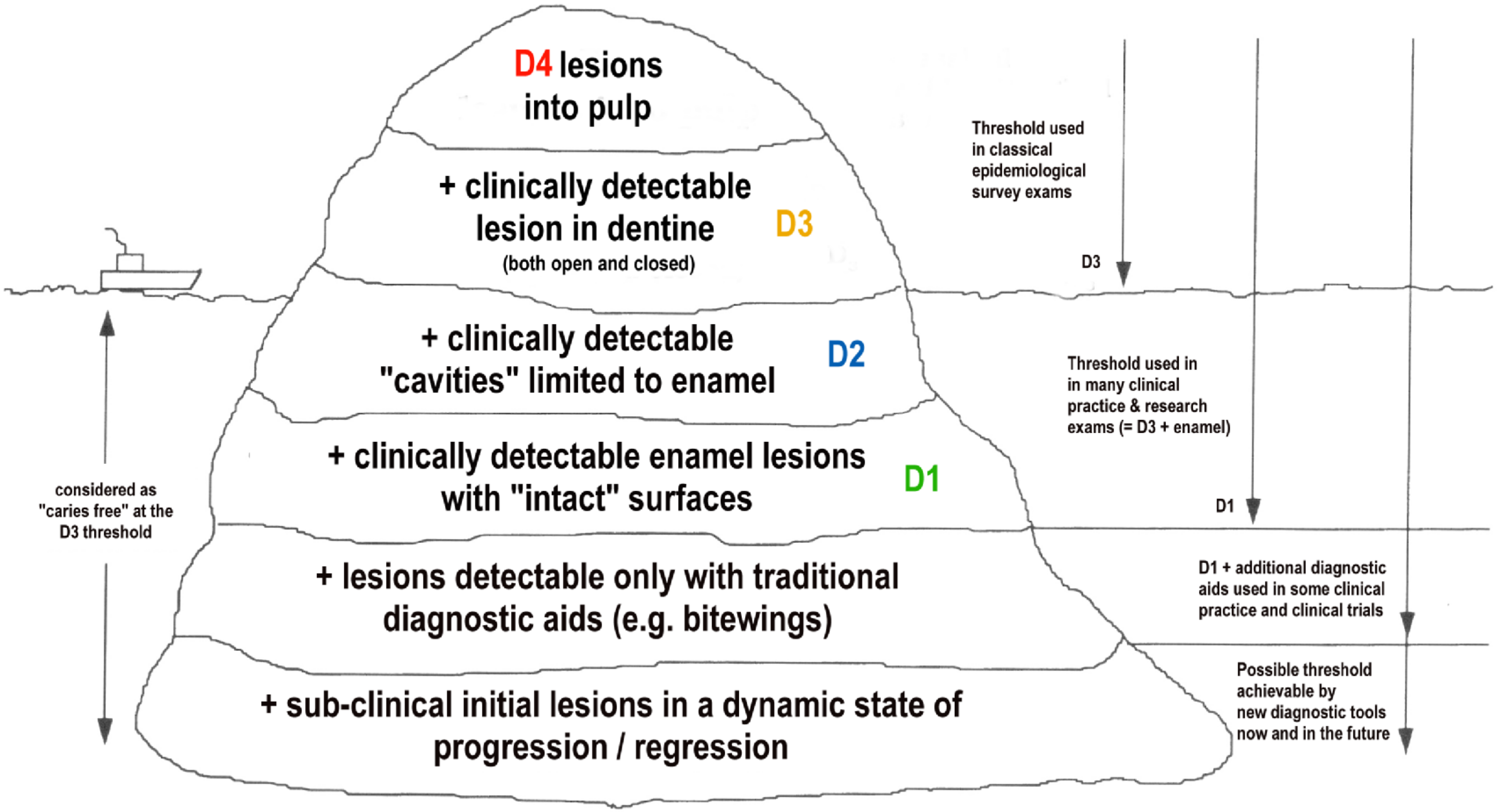
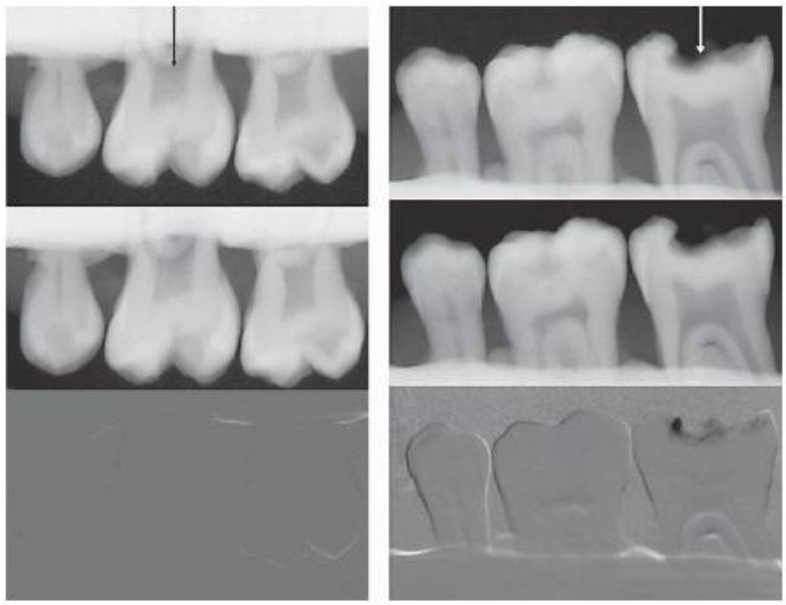


Figure 1.2. An example of subtraction radiography (From Ricketts 2007).



In Figure 1.2, the top of each column is the baseline digital image. The image below is an image taken after possible demineralization with acid for the two teeth arrowed. This is how the images would have been viewed side by side. The image on the bottom is the corresponding subtraction image. The subtraction image shown on the left shows no demineralization, whilst the subtraction image on the right shows clear demineralization.

Fibre Optic Transillumination (FOTI and DiFOTI)

Sound enamel is comprised of modified hydroxyapatite crystals that are densely packed in a crystal lattice. This produces an almost transparent structure. When the enamel structure is disturbed and the enamel is disrupted the penetrating photons of light are scattered, which results in a change in the optical properties of the enamel. Under normal lighting conditions this manifests as a white spot. This appearance is enhanced if water is removed from the lesion by drying the tooth. Water has a similar refractive index (RI) to enamel, but when water is removed by drying, it is replaced by air in the lesion which has a much lower RI than enamel and the appearance of the white spot becomes more profound. This demonstrates the importance of ensuring the clinical caries examinations are undertaken on clean, dry teeth (Cortes, Ellwood et al. 2003).

Fibre optic transillumination (FOTI) enhances these optical properties of enamel by using a high intensity white light that passes through a small aperture. Light is shone through the tooth and shadows in enamel and dentine, resulting from the scattering of light, can be seen. This assists the operator to discriminate between early enamel and early dentine lesions. An additional benefit of FOTI is that it can be used for the detection of caries on all surfaces, particularly proximal lesions.

There are limitations with the FOTI system. The system remains subjective rather than objective, there is no continuous data outputted and it is not possible to directly record what is seen in the form of an image. This makes the longitudinal monitoring of lesions problematic. In order to address some of these concerns digital imaging FOTI (DiFOTI) an imaging version of FOTI has been developed. DiFOTI system comprises of a high intensity light and grey scale camera. Images are displayed on a computer monitor and can be archived for retrieval. However, the system remains subjective with a decision based on the appearance of scattering.

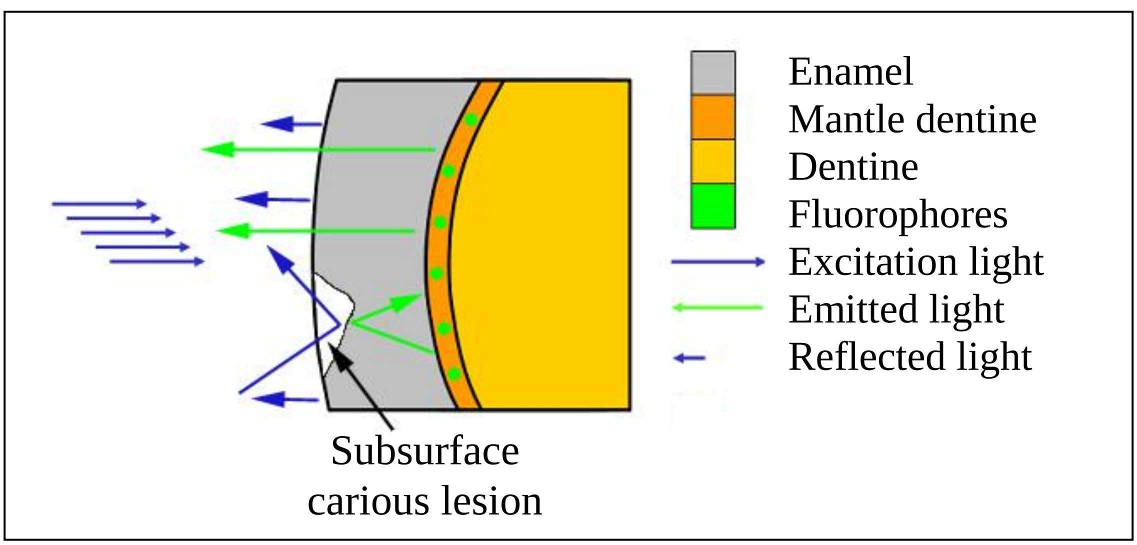
Intra Oral Photography

It is possible to capture images of teeth by the use of an intra oral camera and image capture software. This offers no direct benefit in the detection of caries (other than a greatly magnified image of the dentition), and subsequent examination of images remains subjective. However, the capturing of images does provide the researcher some benefits (Sundfeld, Mauro et al. 2004). The fact that images can be examined remotely from the subject enables the images to be randomized and blinded thus reducing the potential for bias. In addition, computer software can archive and retrieve images for longitudinal monitoring of lesions. This can be further enhanced by the use of video repositioning software (Romane, Bendika et al. 2005).

Quantitative Light-Induced Fluorescence

Quantitative light-induced fluorescence (QLF) is a visible light system that provides the potential to detect and monitor early carious lesions. Fluorescence is a phenomenon by which an object is excited by a particular wavelength of light and the resultant fluorescent (reflected) light is of a larger wavelength. The fluorescent light will be of a different colour to the incident light when the excitation light is in the visible spectrum. In the case of the QLF the visible light has a wavelength of 370 nm, in the blue region of the visible spectrum. The resultant auto-fluorescence of human enamel is then detected by filtering out the excitation light using a bandpass filter at a wavelength greater than 540 nm. This produces an image that is comprised of only green and red channels (the blue is filtered out) and the predominate colour of the enamel is green (de Josselin de Jong, Sundstrom et al. 1995; Ando, Hall et al. 1997). When dental enamel is demineralized, it results in a reduction of auto-fluorescence. This loss can be quantified using proprietary software (van der Veen and de Josselin de Jong 2000). The source of the auto-fluorescence is thought to be the enamel dentinal junction (EDJ). Excitation light passes through the enamel and excites fluorophores contained within the EDJ (van der Veen and de Josselin de Jong 2000). Fluorescence is reduced in demineralized enamel by the scattering effect of the lesion resulting in less excitation light reaching the EDJ in the area of enamel disruption. In addition the fluorescence from the EDJ is back scattered as it attempts to pass through the lesion. This is illustrated in Figure 1.3.

Figure 1.3. Illustration of fluorescence loss with a demineralized enamel lesion



Proprietary QLF equipment (Inspektor Research Systems bv, the Netherlands) is comprised of a light box containing a xenon bulb and a handpiece. Images are displayed via a computer and accompanying software enables patient's details to be entered and individual images of the teeth of interest to be captured and stored.

Analysis of the QLF image can provide a quantitative assessment of the level of demineralization or re-mineralization of a tooth. This is achieved using proprietary software to define areas of sound enamel around the lesion of interest. The software then uses the pixel values of the sound enamel to reconstruct the surface of the tooth and subtracts pixels which are considered to form a lesion. The software then calculates the average fluorescence loss in the lesion, known as ΔF this measures the depth of a lesion, and then the total area of the lesion in mm^2, the product of these two variables results in a third metric output, ΔQ which is the volume of the lesion. During the longitudinal monitoring of lesions, the QLF device employs a video repositioning system that enables the precise positioning of the original image to be replicated on subsequent visits.

The QLF system can offer additional benefits beyond those of very early lesion detection and quantification, such as the ability to archive images for longitudinal analysis. Within the field of clinical research, the ability to remotely analyze lesions enables increased legitimacy in trials by introducing blinding and randomization of assessments which in turn can reduce bias.

It has been well established that the benefits of fluoride in caries prevention are associated with an increased risk of enamel fluorosis if there is excessive systemic fluoride during amelogenesis (Thylstrup and Fejerskov 1978; Fejerskov, Manji et al. 1990; Fejerskov, Larsen et al. 1994; Hong, Levy et al. 2006; Hong, Levy et al. 2006). Fluorosis can be listed in a larger group of presentations known as Developmental Defects of Enamel (DDE). Developmental defects are studied for a variety of reasons; to assess aetiology, to examine markers for fluoride exposure, and to assess prevalence and severity. Various indices exist and the selection of the most appropriate index will be determined by the objectives of the study and which index meets the needs of the research question.

The indices can be broadly separated into those that assume the aetiology for an enamel defect and ignore other features e.g. fluorosis indices, and those indices that do not account for aetiology and merely base the score upon the appearance of the defect e.g. descriptive indices. The descriptive indices are probably more appropriately termed non-causal, or non-aetiological indices as they require visual criteria in the same manner as the fluorosis indices (Ellwood 1993). The major indices are listed in Table 1.1 and have been the subject of reviews in the literature (Clarkson 1989; Rozier 1994).

Both categories of indices have strengths and weaknesses. The non-causal indices may not be specific to fully investigate dental fluorosis, but are able to record a range of enamel defects. This is a contrast with the fluorosis indices that enable the recording of enamel defects linked to fluoride exposure but may not represent the full range of enamel defects expressed within a population.

Table 1.1: Clinical indices commonly used for fluorosis assessment

Fluorosis Indices		
	Year	Reference
Dean's Index	1942	(Dean, Arnold et al. 1942)
Thylstrup & Fejerskov Index (TF)	1978	(Thylstrup and Fejerskov 1978)
Tooth Surface Index of Fluorosis (TSIF)	1984	(Horowitz, Driscoll et al. 1984)
Fluorosis Risk Index (FRI)	1990	(Pendrys 1990)
Non-aetiological (Descriptive) Indices		
	Year	Reference
Young	1973	(Young 1973)
Al-Alousi	1975	(Al-Alousi, Jackson et al. 1975)
Jackson	1975	(Jackson, James et al. 1975)
Murray and Shaw	1979	(Murray and Shaw 1979)
Developmental Defects of Enamel (DDE)	1989	(Clarkson and O'Mullane 1989)

Studies have compared the use of the different clinical indices and the information obtained from them (Wenzel and Thylstrup 1982; Driscoll, Horowitz et al. 1986; Ellwood, O'Mullane et al. 1994). A review of the literature by Rozier (1994) examined the use of the popular indices used in published studies looking at the reported prevalence at various levels of water fluoride content as determined by the various indices. The findings for prevalence are shown in Table 1.2. Direct comparison of Dean’s Index and TF Index for prevalence showed reasonable comparison, on the whole. However, the TF Index appeared to be more sensitive when looking at measurements of severity. It would appear to be advisable to use the TF Index in epidemiological studies as it has increased sensitivity at higher levels of fluorosis, and the drying of teeth would facilitate the discrimination of mild forms of fluorosis at lower levels of fluoride exposure and hence enable possible separation of populations with smaller sample sizes, or where differences in effects are low, for example with fluoride dentifrice use in developed countries.

Where Dean’s Index was compared to TSIF, the latter, again, appeared more sensitive at higher fluoride levels and also showed an increased prevalence when examining the same population. The TSIF has an additional benefit in as much as there is an aesthetic component.

All of the indices discussed have been used extensively in epidemiology. Each index has positive and negative aspects to its use and interpretation. All of the indices can be assessed for reproducibility, sensitivity and reliability between examiners and within an individual examiner. It is possible to achieve high levels of agreement. However, one fact remains; all of the indices are subjective and as a result are open to individual interpretation and variance. It is often not possible to blind an examiner to the status of fluoride exposure and consequently there is often a possibility that bias may enter into the study analysis (NHS-CRD 2000). Rozier (1994) concluded that very little data had been generated looking at the reliability of indices, fewer than half of the reported studies recorded any measure of reliability.

Table 1.2: Comparison of fluorosis indices from Rozier (1994).

PREVALENCE OF DENTAL FLUOROSIS
DERIVED FROM STUDIES COMPARING PI, TF, AND TSIF

Study	Fluoride (ppm) in Drinking Water	Percent Affected		
		Deans Index	TF	TSIF
Thylstrup & Fejerskov (1978)	3.5, 6.0, 21.0	100	100	
Wenzel & Thylstrup (1982)	<0.2	3	5	
Granath *et al* (1985)	0.2	20	24	
Burger *et al* (1987)+	1.6	15*	15*	
Driscoll *et al* (1986)	Optimal	44		60**
Horowitz *et al* (1984)	2x Optimal	82		88
	3x Optimal	77		91
	4x Optimal	87		97
Cleaton-Jones & Hargreaves (1990)	1.56	67	51**	45***

+Primary teeth, not dried for either index.
*Percent of teeth affected.
**Maximum TSIF score.
***Percent of surfaces affected.

An examiner may have an impression as to the fluoridation status and socio-economic status simply from the geographical location of assessments or the physical appearance of the subjects, for example from school uniform. This may impart a level of bias on assessments. Attempts have been made to address the issue of blinding which range from remote assessment of randomized photographic images to relocating subjects for assessment and disguising appearances such as school uniforms (Stephen, Macpherson et al. 2002; Tavener, Davies et al. 2007).

The fact remains, whilst there have been advances in the research field in the early detection and quantification of caries, there has been little advance in the field of fluorosis in terms of quantification and a reliance on subjective indices persists even when employing standardized methodologies (Cochran, Ketley et al. 2004; Cochran, Ketley et al. 2004).

QLF in the Quantification of Dental Fluorosis

The application of QLF in the detection and quantification of carious lesions has been previously discussed. The technologies employed in the QLF system have the scope and potential to be used in alternative fields for detection and quantification (Amaechi and Higham 2002). Studies have been conducted using QLF to detect dental plaque (Romane, Bendika et al. 2005; Coulthwaite, Pretty et al. 2006), and to examine dental stain or tooth whiteness (Pretty, Edgar et al. 2001; Amaechi and Higham 2002; Pretty, Edgar et al. 2004).

Dental fluorosis presents as a surface hypomineralization of enamel. This is not entirely dissimilar to the presentation of early enamel lesions and as such the principles behind the use of QLF in caries detection and quantification can be employed in the quantification of fluorosis (Pretty, Tavener et al. 2006). The major difficulty that needed to be overcome was that the methods used to quantify caries using the QLF system could not be used to quantify fluorosis. The QLF system utilized software to reconstruct the surface of the tooth in order to "subtract" the lesion and provide metrics for the area (mm^2), depth ($\%\Delta F$), and volume (ΔQ) of the lesion. This is possible with a caries lesion as they are generally well defined. However, the appearance of fluorosis is of diffuse opacities across the tooth surface (Ellwood and O'Mullane 1995). This creates difficulties for proprietary QLF software in reconstructing a sound tooth surface. As a result, a bespoke imaging system was created with software designed to address this situation (Pretty, Tavener et al. 2006).

Image blurring is applied in order to produce an average value from sound enamel from the green channel of the bitmap image obtained. Blurring involves the averaging of pixels within a matrix of pre-determined size. The greater the size of the matrix, the larger the blur effect as more pixels are averaged. Once the blurring process is complete, the "unsharp-mask" that is produced is subtracted from the original image leaving those areas considered to be fluorosis. This is illustrated in Figure 1.3.

This system is not perfect as artifacts can be produced, but it is an important step in the process of being able to objectively quantify fluorosis and remove the subjectivity employed in the use of clinical indices (Pretty, Tavener et al. 2006). Furthermore, as in the case of caries quantification, the use of QLF in the quantification may remove the issues associated with criticisms with respect to randomization and blinding that are associated with the use of indices.

Figure 1.3: Example of a completed QLF analysis.

a Original fluorescent image. **b** Clinical image.
c Blur at 30. **d** Blur at 60. **e** Blur at 90.**f** 1 SD.
g 2 SDs. **h** 3 SDs. **i** 4 SDs. **j** Completed analysis demonstrating areas identified as fluorosis with associated metric output.
(From Pretty, Tavener et al 2006)

Aims and Objectives

To measure the prevalence and severity of enamel fluorosis at differing levels of fluoride exposure.

To assess the ability of a fluorescence imaging system to detect a dose response relationship between the levels of fluoride in community water supplies and enamel fluorosis through the objective scoring of images to discriminate between populations.

To assess subject perception of dental aesthetics by adolescents served by either fluoridated or non-fluoridated drinking water.

To determine the prevalence of caries (including caries lesions restricted to enamel) and enamel fluorosis in areas that are served by either fluoridated or non-fluoridated drinking water using clinical scoring, remote blinded, photographic scoring and fluorescence imaging (fluorosis).

To determine the effect of social deprivation on oral health equality and the influence of water fluoridation on the prevalence of caries (including caries lesions restricted to enamel) and enamel fluorosis in areas that are served by either fluoridated or non-fluoridated drinking water using remote, blinded methodologies to minimize the effect of examiner bias.

References

Al-Alousi, W., D. Jackson, et al. (1975). "Enamel mottling in a fluoride and in a non-fluoride community. A study." Br Dent J **138**(2): 56-60.

Amaechi, B. T. and S. M. Higham (2002). "Quantitative light-induced fluorescence: a potential tool for general dental assessment." J Biomed Opt **7**(1): 7-13.

Ando, M., A. F. Hall, et al. (1997). "Relative ability of laser fluorescence techniques to quantitate early mineral loss in vitro." Caries Res **31**(2): 125-31.

Bader, J. D., D. A. Shugars, et al. (2001). "Systematic reviews of selected dental caries diagnostic and management methods." J Dent Educ **65**(10): 960-8.

Brunelle, J. A. and J. P. Carlos (1990). "Recent trends in dental caries in U.S. children and the effect of water fluoridation." J Dent Res **69 Spec No**: 723-7; discussion 820-3.

Carmichael CL, Rugg-Gunn AJ, et al. (1989). "The relationship between fluoridation, social class and caries experience in 5 year old children in Newcastle and Northumberland in 1987." British Dental Journal **167**: 57-61.

Chankanka, O., S. M. Levy, et al. (2010). "A literature review of aesthetic perceptions of dental fluorosis and relationships with psychosocial aspects/oral health-related quality of life." Community Dent Oral Epidemiol **38**(2): 97-109.

Chesters, R. K., N. B. Pitts, et al. (2002). "An abbreviated caries clinical trial design validated over 24 months." J Dent Res **81**(9): 637-40.

Clarkson, J. (1989). "Review of terminology, classifications, and indices of developmental defects of enamel." Adv Dent Res **3**(2): 104-109.

Clarkson, J. and D. O'Mullane (1989). "A modified DDE Index for use in epidemiological studies of enamel defects." J Dent Res **68**(3): 445-50.

Cochran, J. A., C. E. Ketley, et al. (2004). "A comparison of the prevalence of fluorosis in 8-year-old children from seven European study sites using a standardized methodology." Community Dent Oral Epidemiol **32 Suppl 1**: 28-33.

Cochran, J. A., C. E. Ketley, et al. (2004). "A standardized photographic method for evaluating enamel opacities including fluorosis." Community Dent Oral Epidemiol **32 Suppl 1**: 19-27.

Cortes, D. F., R. P. Ellwood, et al. (2003). "An in vitro comparison of a combined FOTI/visual examination of occlusal caries with other caries diagnostic methods and the effect of stain on their diagnostic performance." Caries Res **37**(1): 8-16.

Coulthwaite, L., I. A. Pretty, et al. (2006). "The microbiological origin of fluorescence observed in plaque on dentures during QLF analysis." Caries Res **40**(2): 112-6.

de Josselin de Jong, E., F. Sundstrom, et al. (1995). "A new method for in vivo quantification of changes in initial enamel caries with laser fluorescence." Caries Res **29**(1): 2-7.

Dean, H. T., F. A. Arnold, et al. (1942). "Domestic water and dental caries. V. Additional studies of the relation of fluoride domestic waters to dental caries experience in 4,425 white children aged 12-14 years of 13 cities in 4 states." Public Health Rep **57**: 1155-79.

DOH (1999). "Saving Lives: A Healthier Nation." ISBN 0101438621.

Driscoll, W. S., H. S. Horowitz, et al. (1986). "Prevalence of dental caries and dental fluorosis in areas with negligible, optimal, and above-optimal fluoride concentrations in drinking water." J Am Dent Assoc **113**(1): 29-33.

Ellwood, R. (1993). "Dental Enamel Opacities and the Relationship to Dental Caries " Department of Preventive and Paediatric Dentistry **Cork, University College Cork**.

Ellwood, R., D. O'Mullane, et al. (1994). "A comparison of information recorded using the Thylstrup Fejerskov index, Tooth Surface Index of Fluorosis and Developmental Defects of Enamel index." Int Dent J **44**(6): 628-36.

Ellwood, R. P. and D. O'Mullane (1995). "Enamel opacities and dental esthetics." J Public Health Dent **55**(3): 171-6.

Featherstone, J. D. (2004). "The continuum of dental caries--evidence for a dynamic disease process." J Dent Res **83 Spec No C**: C39-42.

Fejerskov, O., M. J. Larsen, et al. (1994). "Dental tissue effects of fluoride." Adv Dent Res **8**(1): 15-31.

Fejerskov, O., F. Manji, et al. (1990). "The nature and mechanisms of dental fluorosis in man." J Dent Res **69 Spec No**: 692-700; discussion 721.

Hinds, K. and J. R. Gregory (1995). "National Diet and Nutrition Survey: Children Aged 1½ to 4½ Years." HMSO,London,Report of the Dental Survey.

Hong, L., S. M. Levy, et al. (2006). "Timing of fluoride intake in relation to development of fluorosis on maxillary central incisors." Community Dent Oral Epidemiol **34**(4): 299-309.

Hong, L., S. M. Levy, et al. (2006). "Fluoride intake levels in relation to fluorosis development in permanent maxillary central incisors and first molars." Caries Res **40**(6): 494-500.

Horowitz, H. S., W. S. Driscoll, et al. (1984). "A new method for assessing the prevalence of dental fluorosis--the Tooth Surface Index of Fluorosis." J Am Dent Assoc **109**(1): 37-41.

Ismail, A. I. (2004). "Visual and Visuo-tactile Detection of Dental Caries." J Dent Res **83**(suppl_1): C56-66.

Ismail, A. I., W. Sohn, et al. (2007). "The International Caries Detection and Assessment System (ICDAS): an integrated system for measuring dental caries." Community Dent Oral Epidemiol **35**(3): 170-8.

Jackson, D., P. M. James, et al. (1975). "Fluoridation in Anglesey. A clinical study." Br Dent J **138**(5): 165-71.

Maupome, G. and I. A. Pretty (2004). "A closer look at diagnosis in clinical dental practice: part 4. Effectiveness of nonradiographic diagnostic procedures and devices in dental practice." J Can Dent Assoc **70**(7): 470-4.

MRC (2002). Medical Research Council Working Group Report. Water fluoridation and health. London, MRC.

Murray, J. J. and L. Shaw (1979). "Classification and prevalence of enamel opacities in the human deciduous and permanent dentitions." Arch Oral Biol **24**(1): 7-13.

NHS-CRD (2000). A Systematic Review of Public Water Fluoridation. York, The University of York, NHS Centre for Reviews and Dissemination (Report 18).

Pendrys, D. G. (1990). "The fluorosis risk index: a method for investigating risk factors." J Public Health Dent **50**(5): 291-8.

Pitts, N. (2004). ""ICDAS"--an international system for caries detection and assessment being developed to facilitate caries epidemiology, research and appropriate clinical management." Community Dent Health **21**(3): 193-8.

Pitts, N. B. (1997). "Diagnostic tools and measurements--impact on appropriate care." Community Dent Oral Epidemiol **25**(1): 24-35.

Pitts, N. B. (2001). "Clinical diagnosis of dental caries: a European perspective." J Dent Educ **65**(10): 972-8.

Pitts, N. B. (2004). "Modern concepts of caries measurement." J Dent Res **83 Spec No C**: C43-7.

Pitts, N. B., D. J. Evans, et al. (1997). "British Association for the Study of Community Dentistry (BASCD) diagnostic criteria for caries prevalence surveys-1996/97." Community Dent Health **14 Suppl 1**: 6-9.

Pitts, N. B. and H. E. Fyffe (1988). "The effect of varying diagnostic thresholds upon clinical caries data for a low prevalence group." J Dent Res **67**(3): 592-6.

Pitts, N. B. and J. W. Stamm (2004). "International Consensus Workshop on Caries Clinical Trials (ICW-CCT)--final consensus statements: agreeing where the evidence leads." J Dent Res **83 Spec No C**: C125-8.

Pretty, I. A. (2006). "Caries detection and diagnosis: novel technologies." J Dent **34**(10): 727-39.

Pretty, I. A., W. M. Edgar, et al. (2001). "The use of QLF to quantify in vitro whitening in a product testing model." Br Dent J **191**(10): 566-9.

Pretty, I. A., W. M. Edgar, et al. (2004). "A study to assess the efficacy of a new detergent free, whitening dentifrice in vivo using QLF planimetric analysis." Br Dent J **197**(9): 561-6; discussion 551.

Pretty, I. A., J. A. Tavener, et al. (2006). "Quantification of dental fluorosis using fluorescence imaging." Caries Res **40**(5): 426-34.

Ricketts, D. N., K. R. Ekstrand, et al. (2002). "Relating visual and radiographic ranked scoring systems for occlusal caries detection to histological and microbiological evidence." Oper Dent **27**(3): 231-7.

Ricketts, D. N., K. R. Ekstrand, et al. (2007). "Accuracy and reproducibility of conventional radiographic assessment and subtraction radiography in detecting demineralization in occlusal surfaces." Caries Res **41**(2): 121-8.

Romane, D., Z. Bendika, et al. (2005). "The effect of video repositioning on the reliability of light-induced fluorescence imaging: an in vivo study." Caries Res **39**(5): 397-402.

Rozier, R. G. (1994). "Epidemiologic indices for measuring the clinical manifestations of dental fluorosis: overview and critique." Adv Dent Res **8**(1): 39-55.

Rugg-Gunn AJ, Carmichael CL, et al. (1977). "Fluoridation in Newcastle and Northumberland: a clinical study of 5-year-old children. ." British Dental Journal **142**: 359-402.

Stephen, K. W., L. M. Macpherson, et al. (2002). "A blind caries and fluorosis prevalence study of school-children in naturally fluoridated and nonfluoridated townships of Morayshire, Scotland." Community Dent Oral Epidemiol **30**(1): 70-9.

Sundfeld, R. H., S. J. Mauro, et al. (2004). "Clinical/photographic evaluation of a single application of two sealants after eleven years." Bull Tokyo Dent Coll **45**(2): 67-75.

Tavener, J., R. M. Davies, et al. (2007). "Agreement amongst examiners assessing dental fluorosis from digital photographs using the TF index." Community Dent Health **24**(1): 21-5.

Thylstrup, A. and O. Fejerskov (1978). "Clinical appearance of dental fluorosis in permanent teeth in relation to histologic changes." Community Dent Oral Epidemiol **6**(6): 315-28.

van der Veen, M. H. and E. de Josselin de Jong (2000). "Application of quantitative light-induced fluorescence for assessing early caries lesions." Monogr Oral Sci **17**: 144-62.

Wenzel, A., N. Pitts, et al. (1993). "Developments in radiographic caries diagnosis." J Dent **21**(3): 131-40.

Wenzel, A. and A. Thylstrup (1982). "Dental fluorosis and localized enamel opacities in fluoride and nonfluoride Danish communities." Caries Res **16**(4): 340-8.

Whelton, H., E. Crowley, et al. (2006). "Dental caries and enamel fluorosis among the fluoridated population in the Republic of Ireland and non fluoridated population in Northern Ireland in 2002." Community Dent Health **23**(1): 37-43.

Whelton, H., E. Crowley, et al. (2004). "Dental caries and enamel fluorosis among the fluoridated and non-fluoridated populations in the Republic of Ireland in 2002." Community Dent Health **21**(1): 37-44.

Young, M. A. (1973). "An Epidemiological Study of Enamel Opacities, PhD Thesis." University of London, England.

Further Studies in Caries and Fluorosis

Chapter 2

Literature Review: Dental Update Series Part One, Why Fluoride?

Published Dental Update November 2010.

McGrady MG, Ellwood RP, Pretty IA. Why Fluoride? ***Dent. Update*** **2010; 37: 595-602.**

Dental Public Health

Part One: Why Fluoride?

M.G. McGrady*

BDS, PG Dip

StR/Honorary Lecturer in Dental Public Health, the University Of Manchester

R. P. Ellwood

BDS, MDS, MSc, PhD, FFPH

Professor of Dental Diagnostic Science, Dental Health Unit, the University of Manchester

I.A. Pretty

BDS(Hons), MSc, PhD, MFDSRCS (Ed)

Senior Lecturer in Dental Public Health, the University of Manchester

***Corresponding Author:**

Michael G McGrady

Room 1.030 Coupland 3 Building

School of Dentistry

The University of Manchester

Higher Cambridge Street

Manchester

M13 9PL

Why Fluoride?

Abstract

Fluoride has been used in dentistry for over 100 years for the purpose of preventing dental caries. During this time there has been great debate over the mode of action, the optimum method of delivery, and the potential risks associated with its use. This paper will provide a summary of the history of use of fluoride, the mode of action, benefits and different methods of delivery. It will also discuss the potential risk of dental fluorosis.

Part One

Clinical Relevance

This article aims to provide a background for general practitioners for the appropriate use of fluorides in dentistry, enable them to understand the wider significance of fluoride in dentistry and to be able to answer non-clinical questions raised by patients.

Why Fluoride?

Introduction

The use of fluoride in dentistry for caries prevention has been recorded since the late 19th century. Initially, compounds containing fluoride such as calcium fluoride powders and potassium fluoride pills were used to help prevent caries without any substantial evidence base. Denninger was attributed with the first clinical trial of fluoride containing products, when he suggested that children and pregnant females showed benefits from their use (Cawson and Stocker 1984; Murray, Rugg-Gunn et al. 1991). The initial idea for the use of fluorides in caries prevention came about largely owing to work investigating the detrimental effects of excessive fluoride naturally present in the water supply on teeth. It was this work that led to the discovery of the anti-caries benefits of fluoride (Murray, Rugg-Gunn et al. 1991).

The use of fluoride in dentistry has created great debate over the years concerning; the mode of action, optimum methods of delivery, efficacy, and the safety. There has also been debate over the legal and ethical considerations for the use of fluorides on populations as opposed to an individual basis. The fluoridation of public water supplies has perhaps been the most controversial delivery method.

Water fluoridation is the controlled addition of fluoride to a water supply with a view to preventing dental caries. Water fluoridation has been employed for over fifty years. During the majority of that time fierce debate has taken place between those who advocate water fluoridation, and those who oppose it. In February 2008, the then United Kingdom Secretary of State for Health Alan Johnson stated his intention to promote water fluoridation in areas of England with the highest rates of tooth decay. Once again water fluoridation came to the forefront of the political agenda.

Both of the following statements purport to be accurate:

> *"Fluoridation of community drinking water is a major factor responsible for the decline in dental caries (tooth decay) during the second half of the 20th century.*

> *The history of water fluoridation is a classic example of clinical observation leading to epidemiologic investigation and community-based public health intervention."* (CDC 2000)
>
> **Centers for Disease Control and Prevention, 1999**
>
> *"Fluoridation is the greatest case of scientific fraud of this century. If not of all time."* (Groves 2001)
>
> **Dr. Robert Carton, formerly US Environmental Protection Agency, 1992**

As dental undergraduates we are taught the benefits of fluoride in caries prevention, but those who oppose fluoridation cite that practitioners are not sufficiently educated to be able to answer patient's questions regarding the efficacy and safety of water fluoridation (Groves 2001). Unfortunately, there is evidence to suggest that this may be the case in some instances (Lowry and Adams 2004). Such issues are not assisted by the reporting of fluoride and water fluoridation by the media which can be controversial and sensational at times (Lowry 2000). At present, some members of the general public who express an interest in water fluoridation wish to be informed about water fluoridation plans but view the prospect of a referendum as government avoiding responsibility. The public do not see themselves as the appropriate body to make such policy decisions (Lowry, Thompson et al. 2000). It is clear that the public can be influenced by propaganda which in itself may not be factually correct but persuasive in it's presentation (Lowry 2000). Over the course of three articles we will look at the use of fluorides in the prevention of dental caries and the history of water fluoridation. We will look at the arguments for and against the promotion of water fluoridation in order to give practitioners adequate information on which to base opinions and inform their patients as well as providing answers to the inevitable questions that will be raised.

What is Fluoride?

Fluoride is the ionic form of the trace element fluorine, a member of the halogen group of elements. Despite being a trace element, fluorine is common in the environment reaching the hydrosphere by leaching from soils and rocks into the groundwater. It is the third most common compound air pollutant, the most prevalent fluorine containing compound being hydrofluoric acid, which is readily absorbed in the lungs (Whitford 1989). The fluorine atom has a small radius and is highly electronegative. With rare exceptions, such as calcium fluoride, most ionic forms of fluoride are readily soluble in water (Whitford 1989).

The average person's fluoride intake is mainly from dietary sources from foodstuffs and beverages that may contain fluoride as a result of cultivation or preparation. However, this can vary and studies have shown that the accidental or deliberate swallowing of dental products containing fluoride can result in an intake that exceeds that of dietary intake alone (Whitford 1987; Burt 1992). Freshwater fluoride levels can vary greatly from less than 0.1 part per million (ppm) in some parts of the world to in excess of 100ppm in others. The fluoride content of prepared food can be affected by the fluoride content of the water used in preparation. This is particularly important with the reconstitution of infant formulae with fluoridated water (Johnson and Bawden 1987). The dietary fluoride intake alone of a 2-year-old Western Hemisphere child can be around 0.04 – 0.05mg/kg/day (but there can be considerable variation within individuals over time) (Levy, Warren et al. 2001). The fluoride intake will vary in different parts of the world where staple diets vary and the fluoride levels may differ greatly in local water supplies (Venkateswara and Mahajan 1990; Nohno, Sakuma et al. 2006).

On consumption, the rate of absorption is inversely related to pH and follows first order kinetics i.e. the rate of reaction is dependent upon the concentration of fluoride present. Generally, the majority of fluoride is absorbed in the stomach and the remainder in the upper small intestine. Gastric absorption of fluoride occurs more rapidly and is almost complete in the absence of divalent and trivalent cations such as calcium, magnesium and aluminium. These tend to form less soluble salts with fluoride and their absorption in the stomach is reduced. Where higher pH limits gastric absorption, the smaller intestine balances by increasing absorption (Messer and Ophaug 1993).

Benefits of Fluoride

The benefits of the use of fluoride in the prevention of caries were discovered by the observations of early work by figures such as McKay, Black and Dean (Black 1916; McKay 1928; Dean, Arnold et al. 1942; Dean 2006). The fluoridation of public water supplies was viewed by many to be a landmark in public health as a means of reducing dental caries (Dean, Arnold et al. 1950). During the latter half of the 20th Century the focus moved towards alternative methods of delivering fluoride. The use of fluoride dentifrices now constitutes the most common method of fluoride delivery.

How Fluoride Works (Topical vs Systemic)

Early work focused on the presumption that the important effect of fluoride was borne from the systemic ingestion of fluoride and it's incorporation into developing enamel. Since the 1980's research has started to concentrate on the topical effects of fluoride on the caries process which was considered to be the most significant (Featherstone 2000; Hellwig and Lennon 2004).

There are three principle methods that have been suggested by which fluoride can have a topical effect on dental caries. Firstly, in the presence of fluoride, re-mineralization is encouraged. Secondly, the apatite formed in the presence of fluoride is more resistant to acid attack. Thirdly, fluoride may inhibit bacterial metabolism when it diffuses into acidified plaque as hydrogen fluoride. So fluoride promotes re-mineralization, discourages demineralization and may reduce the action of plaque bacteria by inhibiting their growth (Featherstone 2000). Although the action on plaque bacteria may only be important at high fluoride doses commensurate with fluoridated dentifrices rather than levels found in fluoridated water.

The effects of fluoride on oral bacteria have been studied extensively (Hamilton IR and Bowden GH 1996). A significant discovery was that fluoride in its ionic form is unable to cross the cell membrane. However, when the fluoride is in the form of hydrogen fluoride it can rapidly diffuse into cariogenic bacterial cells (Hamilton IR and Bowden GH 1996). Inside the cell, the hydrogen fluoride dissociates creating an acidic environment and releasing fluoride which inhibits bacterial enzyme activity.

The enamel of teeth is composed of a crystal lattice structure of hydroxyapatite (carbonated apatite). This structure contains impurities either in the lattice structure or in an adsorbed state on the surface of the crystals. Carbonate is present within the crystal lattice causing disturbance to the regular array of the ionic structure of the lattice. This carbonate rich mineral is susceptible to acid attack (Hamilton IR and Bowden GH 1996; Featherstone 2000). During the process of demineralization carbonate is lost and is not replaced in the newly formed mineral during re-mineralization.

During re-mineralization saliva flows over the plaque and raises the pH, neutralizing acids and reverses the processes involved in demineralization. The saliva which is super-saturated with respect to phosphate and calcium encourages mineral to re-enter the crystal lattice structure (ten Cate and Featherstone 1991). The partially de-mineralized surface of the enamel acts as a nucleus for new crystal growth. When fluoride is present it adsorbs onto the growing crystal surface and attracts calcium and phosphate ions. This newly formed mineral excludes carbonate and has a higher resistance to acid degradation than the carbonated apatite that it replaces.

It had been noted that during the formation of artificial caries lesions when fluoride was added to the buffer solutions two things occurred. The rate of lesion progression slowed and the fluoride imparted histological differences to the enamel; a sub-surface enamel lesion with an intact surface zone containing fluoroapatite (ten Cate and Featherstone 1991). It was subsequently shown that fluoride in solution and fluoride containing precipitates produced under acidic conditions reduced the acid solubility of enamel and thus inhibited enamel demineralization. If fluoride is present in an acidic solution surrounding enamel crystals it is readily incorporated onto the surface of carbonated apatite and has a strong protective mechanism against acid dissolution. This will occur when plaque bacteria in the biofilm produce acid and fluoride is present at the tooth surface (ten Cate and Featherstone 1991).

It has been suggested that the fluoride incorporated into teeth during development is less important and is insufficient to play a role in the mechanisms involved in caries protection (Featherstone 2000). The primary effect of fluoride is post-eruptive (Burt 2004). Irrespective of whether fluoride is present within the tooth, on the tooth surface, or in dental plaque or plaque fluid, in terms of caries prevention its presence remains important in an ionic form at the site of a developing lesion (Clarkson 1991).

Delivery Mechanisms of Fluoride

During the 1950's and 1960's, the greatest form of fluoride supplementation was derived from water borne sources. By the 1970's this had been replaced by the increasing availability of fluoridated dentifrices (Proctor and Gamble marketed the first clinically proven fluoride dentifrice in 1955 under the brand name Crest®).

The earliest formulations of fluoridated dentifrice used stannous fluoride as the active ingredient. This had an astringent taste and the potential to cause staining of the teeth. During the 1970's and 1980's there was a move towards sodium monofluorophosphate and sodium fluoride as the active ingredients. During this growth period for dentifrice sales many clinical trials were conducted to assess the efficacy of the various formulations (Clarkson, Ellwood et al. 1993). Debate exists over the clinical benefit of one fluoride species over the other (Bowen 1995; Volpe, Petrone et al. 1995). Reports vary as to which formulation is the most efficacious, or they simply state equivalence. However, on balance provided the products are correctly formulated it is probable that no significant clinical differences exist.

Other delivery systems existed such as rinses, tablets, drops, varnishes, gels, and fortified foodstuffs such as salt, milk and juices. Restorative dental materials were developed with the ability to release fluoride over prolonged periods of time. The early materials included glass-ionomer cements such as Chemfil® and Ketac Fil® that leached fluoride, but had relatively poor aesthetics and mechanical properties when compared to other restorative materials. Newer materials such as compomers and resin-modified glass-inomer cements such as Dyract® and Vitremer® have demonstrated superior aesthetics and also shown fluoride leaching properties (Preston, Mair et al. 1999; Wiegand, Buchalla et al. 2007). It should be stated that after an initial period of rapid fluoride release from these materials, the long term release of fluoride is not as pronounced and there is great variation between material types and also the brand of material.

Potential Risks: Fluorosis

It was known that very high levels of fluoride in water were detrimental. Dean's intention was to find a balance between maximum benefit in caries prevention whilst minimizing the risk of developing significant fluorosis. His work lead to the recommendation that optimum water fluoridation would be 1 – 1.2 ppm fluoride in water supplies (See Figures 2.1 and 2.2). Dental enamel fluorosis is one presentation of a larger group of developmental enamel defects. It is characterized histologically as hypomineralized subsurface enamel and clinically as characteristic enamel opacities (Fejerskov, Silverstone et al. 1975; Fejerskov, Manji et al. 1990; Fejerskov, Larsen et al. 1994; Pendrys 1999). Fluorosis results from the ingestion of sufficiently high levels of fluoride over a prolonged period of time during enamel formation (amelogenesis). The severity is dependent upon the level of fluoride ingestion and the time period over which the ingestion took place. The clinical appearance can range from white flecks across the dentition (resulting from an increase in porosity), through a continuum of increasing severity that involves more of the tooth surface, through to brown discolouration and surface pitting with enamel loss occurring at very high fluoride exposure. This effect may affect only a few teeth of the entire dentition depending upon the length of fluoride exposure. (See Figure 2.3).

Several mechanisms have been suggested that would explain the formation of fluorotic enamel. Popular mechanisms that have been considered are altered protein synthesis, direct effects through interactions with ameloblasts or indirect effects on the extracellular matrix (Den Besten 1999). It had been previously suggested that fluoride could have an effect on calcium homeostasis, but this would seem only to affect individuals who are exposed to sufficiently high enough levels of fluoride to develop skeletal fluorosis (Den Besten 1999).

The effect of fluoride on enamel development results in a number of changes. The earliest sign is an increase in tissue porosity along the striae of Retzius (Fejerskov, Larsen et al. 1994). Clinically this would appear as diffuse lines of opacity following the perikymata. Severity increases with increased exposure to fluoride during enamel development. The surface and, in particular, the subsurface enamel becomes increasingly hypomineralized and increasingly porous. The diffuse lines of opacity would appear widened and begin to merge to produce diffuse patches on the enamel. These patches would appear as confluent chalky white areas of opacity as severity increases. One of the most severe changes observed in man is a subsurface hypomineralized lesion which, in the cervical third of the tooth, extends to the enamel-dentine junction. In the coronal region of the tooth it predominantly affects the outer half of enamel, with the most extensive hypomineralization in the outermost subsurface layers. In the most severe form the entire enamel can be involved.

The most severe forms of fluorosis where there is staining and pitting are now considered to be post-eruptive changes resulting from a weakened enamel structure being exposed to environmental conditions. The structural changes that result in the exposed hypomineralized lesions are also subject to chemical changes within the oral environment (Fejerskov, Larsen et al. 1994).

Owing to the complex nature of contemporary fluoride exposure, it is difficult to establish a dose response relationship for fluoride and fluorosis without conducting heavily controlled and monitored longitudinal clinical trials. However, there is an abundance of historical data from times when the majority of fluoride exposure was water based or via supplements. Reviews of these data have been able to provide estimates of the dose response relationship for fluoride in water to fluorosis (Fejerskov, Manji et al. 1990; Fejerskov, Larsen et al. 1994). These reviews have suggested that there is a strong linear relationship between fluoride dose and dental fluorosis. It is also important to note that it has been shown that there is no critical threshold dose level of fluoride below which minor forms of fluorosis does not occur (Aoba and Fejerskov 2002).

Knowledge of the risk periods associated with the development of fluorosis is important not only for the understanding of the processes involved, but also the reducing the risk of fluorosis when prescribing fluoride with the aim of preventing caries (Banting 1999). The teeth generally considered to be of most concern from an aesthetic point of view are the maxillary permanent central incisors. Historically, studies consistently showed that the risk period for fluorosis for these teeth is a 2-year period through the second and third years of life (Aoba and Fejerskov 2002). However, more recent studies suggested that the risk to central incisors can peak at 6-months and 24-months and are susceptible to fluorosis from birth up to 3-years (Hong, Levy et al. 2006; Hong, Levy et al. 2006). There was also a suggestion that there were differences in the risk periods between the genders with a critical period of between 15–24 months of age for males and 21–30 months of age for females (Evans and Darvell 1995; Ismail and Messer 1996). (See Figure 2.4). However, it must be stressed that these "windows of vulnerability" discussed above are relevant to the maxillary central incisors only and can be misleading when considering the risk of fluorosis in relation to the whole dentition. The contemporary view is that the risk of developing fluorosis is related to the duration of accumulative exposure to high levels of fluoride (Hong, Levy et al. 2006). The reality is that individuals are at risk to developing dental fluorosis across the whole dentition from birth up to the age of 6-8 years. This risk is related to the timing of the fluoride intake relative to the stage of amelogenesis, but also the cumulative dose of fluoride over the period of time of intake for the whole developing dentition not just for the maxillary central incisors.

Since the advent of water fluoridation schemes, and in the light of the widespread use of fluoridated products, the prevalence of fluorosis has increased in both fluoridated and non-fluoridated communities (Clark 1994; Tabari, Ellwood et al. 2000). Fluorosis has been shown to be more prevalent in fluoridated areas than non-fluoridated areas. In Newcastle Upon Tyne (UK) this figure was shown to be 54% compared to 23% in non-fluoridated Northumberland (Tabari, Ellwood et al. 2000), where all subjects with any fluorosis were included. This pattern is repeated in other areas when similar communities are compared (Ellwood and O'Mullane 1995). Debate exists when concepts such as "significant fluorosis" or "aesthetically objectionable fluorosis" are investigated. In the same population in Newcastle where there was a fluorosis prevalence of 54%, the prevalence of aesthetically unacceptable fluorosis was only 3%. Earlier studies had shown that when the Thylstrup and Fejerskov (TF) Index was used, teeth with a TF score of 3 (where diffuse patches of fluorosis are clearly visible) were considered aesthetically unacceptable (Hawley, Ellwood et al. 1996). Generally, aesthetic considerations are only an issue when the upper anterior teeth are involved. Furthermore, it should be noted the methods employed to measure fluorosis will have an impact on outcome. The Thylstrup and Fejerskov Index requires thorough drying of the teeth prior to examination. This will result in highlighting minor forms of fluorotic opacities that might not be visible to the naked eye when the tooth is viewed wet. This is owing to the difference in refractive indices of air, enamel and water (saliva). The refractive indices of enamel and water are similar so when a tooth with mild fluorosis is viewed wet it may be difficult to visualize the fluorotic opacities. When the same tooth is dried thoroughly, saliva is removed from the opacities and replaced with air. As the refractive indices of enamel and air are different the dry porosity will become more apparent. Therefore fluorosis prevalence results within a population using the TF index might be higher than those reported with indices that view teeth wet such as the Tooth Surface Index of Fluorosis (TSIF). Other factors such as lighting and the viewing of photographic images can impact on outcomes. It is relevant to measure the impact of fluorosis by assessing aesthetics, particularly from the point of view of the patient, but in terms of monitoring trends in fluorosis prevalence it is essential to include data from all patients, not just those deemed to have aesthetically objectionable fluorosis.

Discussion

In this paper we have given a brief history of the observations that brought about the use of fluorides in dentistry, initially as water fluoridation, and then as products acting as vehicles for fluoride in the prevention of dental caries. Even from the early days of Dean's work, there have been attempts to address the balance between risk and benefit with respect to the use of fluoride: namely caries prevention and the risk of fluorosis. It is natural that there will always be those who view the relative positions of risk and benefit differently.

The principle that it is the post-eruptive effect of fluoride that is the most significant factor in caries prevention must also be considered. If the effect is post eruptive, then surely the most appropriate thing to do would be to halt systemic forms of fluoridation and use only topical means? The answer to this is less straightforward. Factors relating to efficacy and effectiveness must be considered when comparing the active mechanisms of topical fluoride applications (home use or professional) and the passive nature of fluoride delivery via water fluoridation. There is also evidence to suggest that fluoridated water has a topical effect in caries prevention (Kidd, Thylstrup et al. 1980; Hardwick, Teasdale et al. 1982).

It should also be noted that fluorosis occurs not only from the ingestion of fluoride in drinking water, or foods and beverages prepared with it, but also from the ingestion of fluoride containing products that are intended for topical use. These include mouthrinses, fluoride varnishes, and fluoride dentifrice. It is important to assess the impact these products have on the prevalence of fluorosis (Tavener, Davies et al. 2006).

In the second paper we will look at water fluoridation as a dental public health policy and the evidence base established to endorse its implementation.

References

Aoba, T. and O. Fejerskov (2002). "Dental fluorosis: chemistry and biology." Crit Rev Oral Biol Med **13**(2): 155-70.

Banting, D. W. (1999). "International fluoride supplement recommendations." Community Dent Oral Epidemiol **27**(1): 57-61.

Black, G. V. (1916). "Mottled enamel. An endemic developmental imperfection of the teeth, heretofore unknown in the literature of dentistry." Dental Cosmos **58**: 129-156.

Bowen, W. H. (1995). "The role of fluoride toothpastes in the prevention of dental caries." J R Soc Med. **Sep;88(9)**: 505-7.

Burt, A. B. (2004). "Pre- and Posteruptive Fluoride: Do Both Actions Control Caries?" Journal of Public Health Dentistry **64**(s1): 47-49.

Burt, B. A. (1992). "The changing patterns of systemic fluoride intake." J Dent Res **71**(5): 1228-37.

Cawson, R. A. and I. P. Stocker (1984). "The early history of fluorides as anti-caries agents." Br Dent J **157**(11): 403-4.

CDC. (2000). "From the Centers for Disease Control and Prevention. Achievements in public health, 1900-1999: fluoridation of drinking water to prevent dental caries." Jama **283**(10): 1283-6.

Clark, D. C. (1994). "Trends in prevalence of dental fluorosis in North America." Community Dent Oral Epidemiol **22**(3): 148-52.

Clarkson, B. H. (1991). "Caries prevention--fluoride." Adv Dent Res **5**: 41-5.

Clarkson, J. E., R. P. Ellwood, et al. (1993). "A comprehensive summary of fluoride dentifrice caries clinical trials." Am J Dent **6 Spec No**: S59-106.

Dean, H. T. (2006). "Endemic fluorosis and its relation to dental caries. 1938." Public Health Rep **121 Suppl 1**: 213-9; discussion 212.

Dean, H. T., F. A. Arnold, et al. (1942). "Domestic water and dental caries. V. Additional studies of the relation of fluoride domestic waters to dental caries experience in 4,425 white children aged 12-14 years of 13 cities in 4 states." Public Health Rep **57**: 1155-79.

Dean, H. T., F. A. Arnold, et al. (1950). "Studies on mass control of dental caries through fluoridation of the public water supply." Public Health Rep **65**: 1403-8.

Den Besten, P. K. (1999). " Mechanism and timing of fluoride effects on developing enamel. " J Public Health Dent **59**: 247–51.

Ellwood, R. P. and D. M. O'Mullane (1995). "Dental enamel opacities in three groups with varying levels of fluoride in their drinking water." Caries Res **29**(2): 137-42.

Evans, R. W. and B. W. Darvell (1995). "Refining the estimate of the critical period for susceptibility to enamel fluorosis in human maxillary central incisors." J Public Health Dent **55**(4): 238-49.

Featherstone, J. D. B. (2000). "The Science and Practice of Caries Prevention." J Am Dent Assoc **131**(7): 887-899.

Fejerskov, O., M. J. Larsen, et al. (1994). "Dental tissue effects of fluoride." Adv Dent Res **8**(1): 15-31.

Fejerskov, O., F. Manji, et al. (1990). "The nature and mechanisms of dental fluorosis in man." J Dent Res **69 Spec No**: 692-700; discussion 721.

Fejerskov, O., L. M. Silverstone, et al. (1975). "Histological features of fluorosed human dental enamel." Caries Res **9**(3): 190-210.

Groves, B. (2001). Fluoride drinking ourselves to death? Dublin, Newleaf.

Hamilton IR and Bowden GH (1996). "Fluoride effects on oral bacteria." In: Fejerskov O, Ekstrand J, Burt BA, eds. Fluoride in dentistry. Copenhagen, Denmark: Munksgaard: 230-51.

Hardwick, J. L., J. Teasdale, et al. (1982). "Caries increments over 4 years in children aged 12 at the start of water fluoridation." Br Dent J **153**(6): 217-22.

Hawley, G. M., R. P. Ellwood, et al. (1996). "Dental caries, fluorosis and the cosmetic implications of different TF scores in 14-year-old adolescents." Community Dent Health **13**(4): 189-92.

Hellwig, E. and A. M. Lennon (2004). "Systemic versus topical fluoride." Caries Res **38**(3): 258-62.

Hong, L., S. M. Levy, et al. (2006). "Timing of fluoride intake in relation to development of fluorosis on maxillary central incisors." Community Dent Oral Epidemiol **34**(4): 299-309.

Hong, L., S. M. Levy, et al. (2006). "Fluoride intake levels in relation to fluorosis development in permanent maxillary central incisors and first molars." Caries Res **40**(6): 494-500.

Ismail, A. I. and J. G. Messer (1996). "The risk of fluorosis in students exposed to a higher than optimal concentration of fluoride in well water." J Public Health Dent **56**(1): 22-7.

Johnson, J., Jr. and J. W. Bawden (1987). "The fluoride content of infant formulas available in 1985." Pediatr Dent **9**(1): 33-7.

Kidd, E. A., A. Thylstrup, et al. (1980). "Influence of fluoride in surface enamel and degree of dental fluorosis on caries development in vitro." Caries Res **14**(4): 196-202.

Levy, S. M., J. J. Warren, et al. (2001). "Patterns of fluoride intake from birth to 36 months." J Public Health Dent **61**(2): 70-7.

Lowry, R. J. (2000). "Antifluoridation propaganda material--the tricks of the trade." Br Dent J **189**(10): 528-30.

Lowry, R. J. (2000). "What the papers say: how does the United Kingdom press treat water fluoridation and does it matter?" Br Dent J **189**(1): 14-8.

Lowry, R. J. and G. Adams (2004). "Attitudes to water fluoridation in general dental practice in the North East of England." Br Dent J **196**(7): 423-4; discussion 411.

Lowry, R. J., B. Thompson, et al. (2000). "How much do the general public want to be involved in decisions on implementing water fluoridation?" Br Dent J **188**(9): 500-2.

McKay, F. S. (1928). "The relation of mottled enamel to caries." J Am Dent Assoc **15**: 1429-37.

Messer, H. H. and R. H. Ophaug (1993). "Influence of gastric acidity on fluoride absorption in rats." J Dent Res **72**(3): 619-22.

Murray, J. J., A. J. Rugg-Gunn, et al. (1991). "In Fluorides in Caries Prevention" 3rd edition. Oxford: Butterworth-Heinemann Ltd."

Nohno, K., S. Sakuma, et al. (2006). "Fluoride Intake from Food and Liquid in Japanese Children Living in Two Areas with Different Fluoride Concentrations in the Water Supply." Caries Research **40**(6): 487-493.

Pendrys, D. G. (1999). "Analytical Studies of Enamel Fluorosis: Methodological Considerations." Epidemiol Rev **21**(2): 233-246.

Preston, A. J., L. H. Mair, et al. (1999). "Fluoride release from aesthetic dental materials." J Oral Rehabil **26**(2): 123-9.

Tabari, E. D., R. Ellwood, et al. (2000). "Dental fluorosis in permanent incisor teeth in relation to water fluoridation, social deprivation and toothpaste use in infancy." Br Dent J **189**(4): 216-20.

Tavener, J. A., G. M. Davies, et al. (2006). "The prevalence and severity of fluorosis in children who received toothpaste containing either 440 or 1,450 ppm F from the age of 12 months in deprived and less deprived communities." Caries Res **40**(1): 66-72.

ten Cate, J. M. and J. D. Featherstone (1991). "Mechanistic aspects of the interactions between fluoride and dental enamel." Crit Rev Oral Biol Med **2**(3): 283-296.

Venkateswara, K. and C. L. Mahajan (1990). "Fluoride Content of Some Common South Indian Foods and Their Contribution to Fluorosis." J Sci Food Agric **51**: 215-219.

Volpe, A. R., M. E. Petrone, et al. (1995). "Clinical anticaries efficacy of NaF and SMFP dentifrices: overview and resolution of the scientific controversy." J Clin Dent. **6 Spec No**: 1-28.

Whitford, G. M. (1987). "Fluoride in dental products: safety considerations." J Dent Res **66**(5): 1056-1060.

Whitford, G. M. (1989). "The metabolism and toxicity of fluoride." Monogr Oral Sci **13**: 1-160.

Wiegand, A., W. Buchalla, et al. (2007). "Review on fluoride-releasing restorative materials--Fluoride release and uptake characteristics, antibacterial activity and influence on caries formation." Dental Materials **23**(3): 343-362.

Figure 2.1. Dean's 21 city Study illustrating caries reduction benefit at differing water fluoride levels (Source Dean 1942)

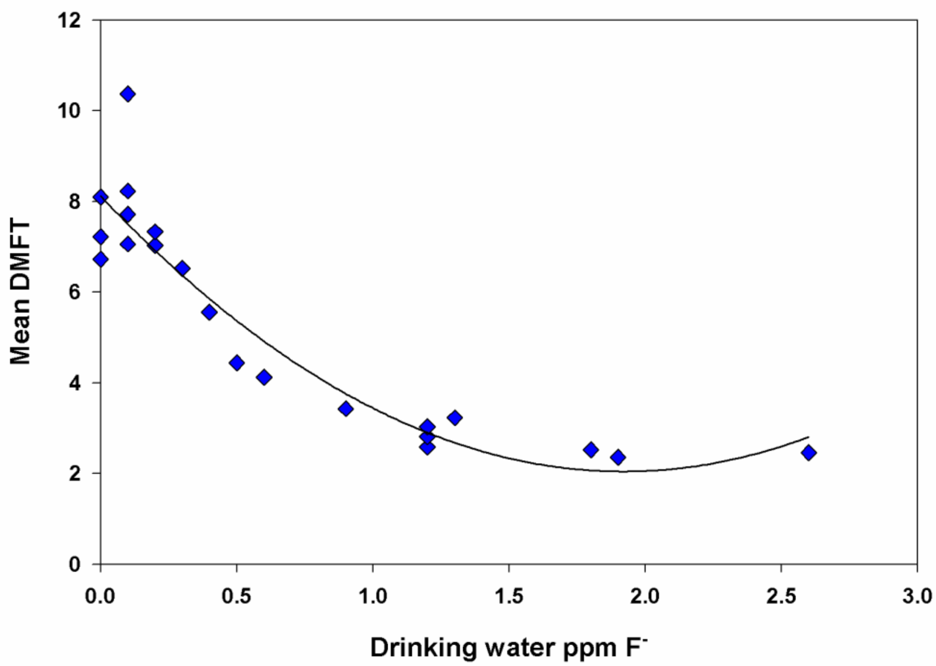


Figure 2.2. Dean’s 21 City Study: Log transformation of the fluoride level in the drinking water and the fluorosis prevalence and severity at differing water fluoride levels (Source Dean 1942).

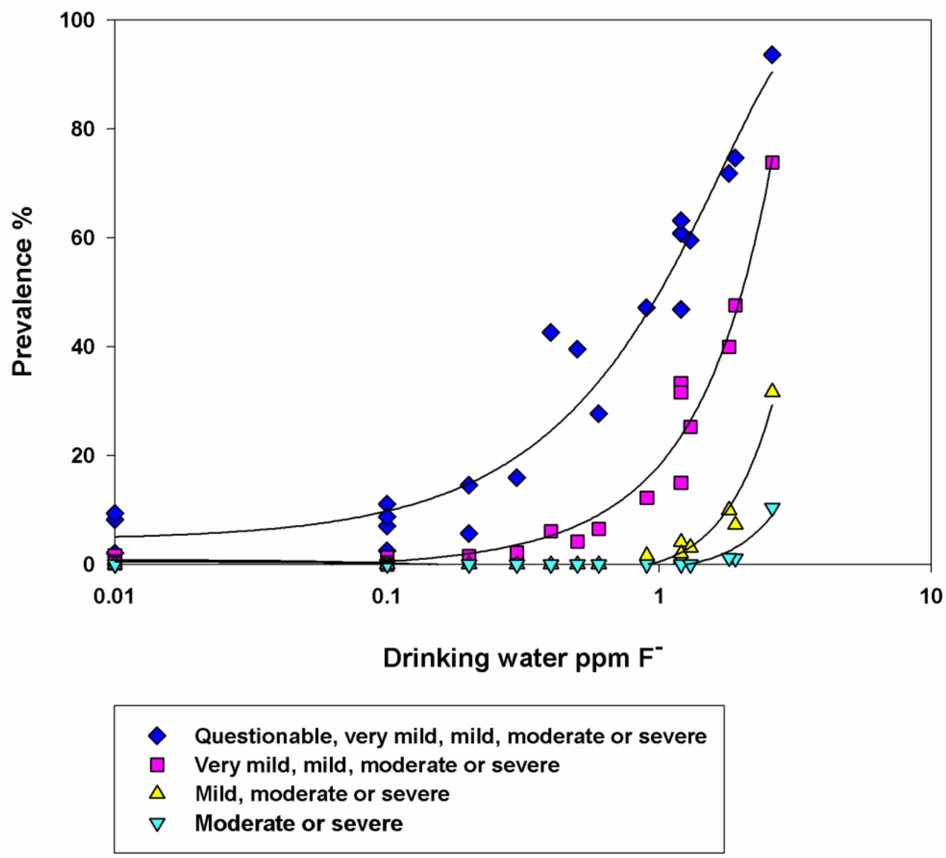


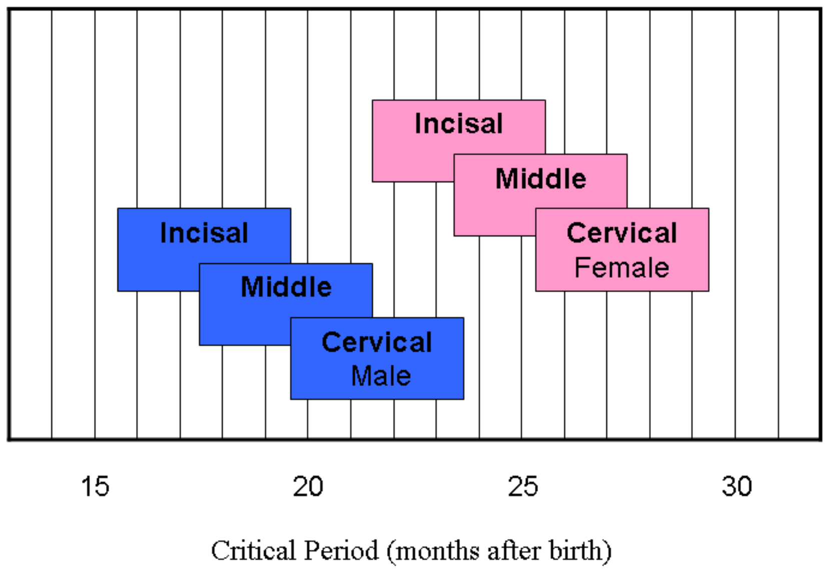
Figure 2.3. Examples of fluorosis severity

Figure 2.3.1. Mild signs of fluorosis highlighting the perikymata. Would probably not be considered aesthetically important.

Figure 2.3.2. More severe fluorosis demonstrating patchy areas across the tooth surface. Could be considered aesthetically significant.

Figure 2.3.3. More extensive fluorosis resulting in confluent areas on the enamel surface with enamel breakdown and staining. Aesthetically significant.

Figure 2.4. Critical Period for Fluorosis for Incisal Edge, Middle and Cervical thirds of Maxillary Incisors (Source: Evans 1995).



Further Studies in Caries and Fluorosis

Chapter 3

Literature Review: Dental Update Series Part Two, Water Fluoridation as a Public Health Measure

Published Dental Update December 2010.

McGrady MG, Ellwood RP, Pretty IA. Water Fluoridation as a Public Health Measure. Dental Update 2010; 37: 658-664.

Dental Public Health

Part Two: Water Fluoridation as a Public Health Measure

M.G. McGrady*

BDS, PG Dip

StR/Honorary Lecturer in Dental Public Health, the University Of Manchester

R. P. Ellwood

BDS, MDS, MSc, PhD, FFPH

Professor of Dental Diagnostic Science, Dental Health Unit, the University of Manchester

I.A. Pretty

BDS(Hons), MSc, PhD, MFDSRCS (Ed)

Senior Lecturer in Dental Public Health, the University of Manchester

***Corresponding Author:**

Michael G McGrady

Room 1.030 Coupland 3 Building

School of Dentistry

The University of Manchester

Higher Cambridge Street

Manchester

M13 9PL

Part 2: Water Fluoridation as a Public Health Measure

Abstract

Water fluoridation schemes have been used as dental public health measures for over 50 years. This paper aims to provide a background to the history of water fluoridation schemes and the evidence base that led to their implementation. The article will also discuss the processes and chemicals involved in fluoridation during water treatment.

Part Two

Clinical Relevance

This article aims to provide a summary for general practitioners for the history and evidence base for water fluoridation, to enable them to understand the role of water fluoridation in caries prevention and to be able to answer non-clinical questions raised by patients.

Paper 2 – Water Fluoridation as a Public Health Measure

Introduction

In the first article we reviewed the history of fluoride in dentistry, and a summary of the mechanisms behind the delivery and the mode of action of fluorides in caries prevention. We also examined the detrimental effects of excessive fluoride on the teeth. In this second article we will look at the early clinical observations and empirical data generated that support water fluoridation and the background for the evidence base that resulted in water fluoridation schemes. This includes the work of Dean who looked at the risk/benefit of water fluoridation to find an optimal level of water fluoride for caries reduction with minimal risk to aesthetically significant dental fluorosis (Dean 1938; Dean, Jay et al. 1939; Dean, Jay et al. 1939; Dean, Arnold et al. 1942; Dean, Arnold et al. 1950). We will also look at the history of water fluoridation schemes and the mechanical processes involved in water fluoridation.

History of Water Fluoridation

At the beginning of the 20th Century a Colorado dentist named Dr. Frederick McKay noted that many of his patients had unique enamel opacities that did not conform to opacities more commonly observed. These opacities were referred to locally as “Colorado Brown Stain”. Despite the fact that on occasions these stains were unsightly, they were generally accepted by the patients, presumably owing to their high prevalence in the population. McKay observed that this stain to be more prevalent in those born either in the district, or had moved there as infants. He thought that some environmental influence was acting during the period of enamel formation and collaborated with the renowned Dr. Greene Vardiman Black to first describe what came to be known as mottled enamel (Black 1916; McKay 1928). It had previously been thought that the mottled teeth may be more susceptible to caries (McKay 1928). However, it was noted that there was no increase caries experience. When McKay became aware of similar cases elsewhere in the United States and around the world, such as Eager’s work in Naples (Murray, Rugg-Gunn et al. 1991), he concluded that the environmental factor at play here was contained within the drinking water.

Around the same time in the United Kingdom in Maldon, Essex a dentist named Norman Ainsworth noticed similar “staining” (what we would now consider to be fluorosis) on teeth. In 1925 Ainsworth examined over 4,000 children as part of a study for the Medical Research Council (Murray, Rugg-Gunn et al. 1991). Ainsworth produced a statistical comparison of caries rates for populations with and without the observed tooth discolouration and concluded that those with more of the “staining” had less caries. The results showed that when looking at all the children, the percentage of permanent teeth with caries was 13.1%. When teeth from Maldon were considered separately, this figure fell to 7.9%. Ainsworth compared the water supplies of Maldon with that of Witham, a nearby town. The results revealed that the water in Maldon had 4.5 – 5.5ppm fluoride compared to 0.5ppm fluoride in the water in Witham (Murray, Rugg-Gunn et al. 1991).

A chemist employed by the Aluminium Company of America, H.V. Churchill employed new spectrographic techniques to analyze water samples from abandoned wells near mines in Bauxite, Arkansas, USA. Levels of fluorine, normally present in soil in very low concentrations (<1.0 ppm), were found in the water of the mine in concentrations of 13.7 ppm. McKay sent water samples to Churchill from areas with endemic mottled enamel for analysis. The results revealed that the samples contained levels of fluoride that ranged from 2.0-12.0 ppm. This did not establish a cause and effect link between water fluoride and mottled enamel, but coupled with the observations of animal data showing fluorosis in rats fed fluoridated water helped establish the link between fluoride and mottled enamel (Churchill 1931).

The discovery of a relationship between mottled enamel and reduced prevalence of dental caries was considered to be important and worthy of further investigation. A series of epidemiological studies carried out by H Trendley Dean confirmed the findings of the earlier reports. By the 1930’s the term “mottled enamel” was being replaced with the term “fluorosis” as the aetiological factor was revealed. Dean developed an ordinal scale based on the clinical presentation of fluorosis (Dean 1934). The original seven grades of severity were subsequently condensed to a six-point scale by combining the moderately severe and severe categories (Dean 1939). By 1942, Dean had mapped the prevalence of fluorosis for most of the United States.

Based upon early observation that milder forms of fluorosis were related to lower than expected caries prevalence, Dean focused his research on the relationship between caries and fluoride. Dean demonstrated that 12-14-year-old children living in communities with water fluoride levels of 1.8 mg F/L (Galesburg and Monmouth, Illinois) had a caries experience less than half that seen in a nearby area with 0.2 mg F/L (Quincy and Macomb). Another observation of this study was that the low level of caries experience in the high fluoride population was accompanied by higher levels of fluorosis.

Meanwhile in the United Kingdom, the Second World War resulted in the evacuation and relocation of children from towns and cities to the countryside. Westmoreland in the Lake District became the temporary home for children from South Shields, a small industrial coastal town in the north east of England. The Senior School Dentist for Westmoreland observed that the evacuees had significantly less caries than the local children (Murray, Rugg-Gunn et al. 1991). Aware of the work being carried out in America, a dentist working for the Ministry of Education, Robert Weaver had the water of South Shields analyzed. It was found to contain 1.4ppm fluoride. The water from North Shields on the opposite side of the river Tyne contained only 0.25ppm fluoride. In 1944 Weaver conducted a study to examine caries rates for North and South Shields. One Thousand children were examined on either side of the river and the results showed much lower caries rates for children in South Shields for deciduous and permanent teeth (Abbott 1966; Mullen 2005).

Evidence Base for Water Fluoridation

Dean set about defining water fluoride levels that would strike the appropriate balance between low caries experience and acceptable levels of fluorosis. The work that followed has become collectively known as the “21 Cities” study (Dean, Arnold et al. 1950).

The 21 Cities study was a landmark study in epidemiology and led to the adoption of 1.0-1.2 mg F/L as the water fluoride level for drinking water in temperate areas of the United States. Although the data were cross-sectional and they could not, on their own, establish cause and effect between reduced caries experience and fluoridated water, the evidence presumed that there was a cause and effect relationship. The stage had now been set for a prospective test of this hypothesis. In 1945, Grand Rapids, Michigan, became the first community to add fluoride to its water supply at a level of 1 ppm (Dean, Arnold et al. 1950). After six and a half years of water fluoridation, the caries experience of the children in Grand Rapids was approximately half that of a control population in Muskegon that had no water fluoridation. The results of this study led to repeated studies across the world with the implementation of water fluoridation as a method of preventing dental caries (Dean, Arnold et al. 1950; Arnold, Dean et al. 2006).

All of the studies conducted by Dean may be described as crude by modern standards. The studies were cross-sectional in design and none were longitudinal (although they did include implementation studies). No attempt was made to account for social status and examiners changed from year to year resulting in possible bias. Despite this, the results of the studies remained consistent and compelling. A fluoride level of 1 ppm in drinking water demonstrated the average number of decayed missing or filled teeth had reduced by more than 50%. This was associated with the observation that there appeared to be little if any fluorosis of "cosmetic significance" below this level of fluoride. The result was the widespread adoption of 1-1.2 ppm as an 'optimal' level of fluoride in drinking water.

The Tiel-Culemborg study in the Netherlands ran from 1953 to 1971 and was one of the first studies to run a longitudinal design (Groeneveld 1985). The study was well controlled and children were examined every two years. Despite the fact that the study ended in 1971, the data has been used repeatedly to examine the effects of fluoride and fluoridated water (Groeneveld, Van Eck et al. 1990). An important finding from Tiel-Culemborg was differences in caries prevalence and severity between the two populations (Backer Dirks, Houwink et al. 1961; Kwant GW, Houwink B et al. 1973). When considering all carious lesions, there were no differences in prevalence between fluoridated Tiel (1ppm fluoride) and non-fluoridated Culemborg (0.1ppm fluoride). However, when the severity of the caries was taken into consideration, there appeared to be differences between the populations. In Tiel 93% of buccal and 86% of approximal lesions had not progressed into dentine. In Culemborg only 65% of buccal and 65% of approximal lesions had not progressed into dentine. In fluoridated Tiel, fewer white spot lesions progressed into cavities than in non-fluoridated Culemborg. The conclusion was that caries progression was markedly reduced in the fluoridated population (Groeneveld 1985).

In 1973 the Supreme Court ruled that there was no legal basis for water fluoridation in the Netherlands. Attempts were made to amend legislation to provide a legal basis for water fluoridation but preparations to amend the Water Supply Act were withdrawn owing to a lack of political support. Water fluoridation ceased in the Netherlands in 1976. Studies subsequent to the removal of fluoridation from Tiel have followed the caries trends (Kalsbeek, Kwant et al. 1993). Caries rates in Tiel increased after fluoridation ceased. DMFS scores increased between 1968/1969 and 1987/1988 but then reduced again, presumably with the widespread use of fluoridated toothpaste. In 1987/1988, the DMFS scores in Tiel were 17% higher than in Culemborg. This observation may have been explained by the more frequent application of fluoride products in Culemborg.

History of Water Fluoridation in the UK

In 1948, the National Health Service was formed. Within this there was provision for free dental treatment to the population. Demand for this service was overwhelming as patients who were put off attending a dentist owing to the expense of private dental treatment now presented themselves to dentists with high levels of disease. This placed tremendous financial pressure on monies available for dental health care provision. Aware of the work of Dean in the USA (Dean, Arnold et al. 1942; Dean, Arnold et al. 1950) and the findings of Ainsworth and Weaver (Murray, Rugg-Gunn et al. 1991), in 1953, the British Government sent a mission to the USA and Canada to look at fluoridation schemes in operation. The findings of the mission recommended schemes in selected communities in order to evaluate water fluoridation. In the 1950s the United Kingdom pilot schemes for water fluoridation were set up in Watford, Kilmarnock and part of Anglesey with control populations in non-fluoridated Sutton, Ayr and the remainder of Anglesey. Studies carried out five years and eleven years after fluoridation showed an increase in the proportion of caries free children and a decrease in the proportion of children with ten or more carious teeth within each fluoridated population when compared to the corresponding non-fluoridated control population . The results of these studies compared favourably with the data obtained from studies in the United States. After initially agreeing to participate in the study, a reversal of this position by the Burgh Council in Kilmarnock ended fluoridation in 1962 after a period of 6 years. The subjects continued to be followed subsequently and caries trends indicated an increase in caries after fluoridation ceased. Anglesey was the setting for numerous fluoridation studies from the initiation of fluoridation in 1955, to the complete fluoridation of the island in 1964, and leading up to the decline and end of the fluoridation project in 1992. The early studies demonstrated the beneficial effect of lower caries rates when compared to non-fluoridated communities, initially on the island, and later on the mainland (Jackson, James et al. 1975; Jackson, James et al. 1985; Seaman, Thomas et al. 1989). During the final years of the fluoridation project on Anglesey studies still demonstrated a benefit even from sub-optimal fluoride levels in water when compared to non-fluoridated communities (Jackson, James et al. 1985; Seaman, Thomas et al. 1989). Fluoridation ended on Anglesey when a decision was taken that the capital investment required to replace aging equipment for water fluoridation was not economically viable (a similar outcome had occurred in Watford during the 1980's). After fluoridation ended, studies demonstrated an increase in caries rates on the island (Hulse, Kenrick et al. 1995).

Birmingham and the West Midlands commenced water fluoridation in 1965. Newcastle and its surrounding area followed shortly after in 1968. Both schemes aimed to provide water supplies with 1ppm fluoride through artificial fluoridation of non-fluoridated water supplies and supplementing naturally fluoridated water supplies to boost or maintain water fluoride levels at 1ppm. Numerous studies followed in both of these regions monitoring caries rates and comparing fluoridated communities with neighboring non-fluoridated communities gathering substantial evidence to promote the benefits of water fluoridation on caries levels (Rugg-Gunn AJ, Carmichael CL et al. 1977; Carmichael, Rugg-Gunn et al. 1980; Carmichael, French et al. 1984; French, Carmichael et al. 1984; Murray, Gordon et al. 1984; Mitropoulos, Lennon et al. 1988; Rugg-Gunn, Carmichael et al. 1988; Carmichael CL, Rugg-Gunn AJ et al. 1989).

Despite the wealth of evidence supporting the introduction of water fluoridation and the impact on dental decay levels, Birmingham and Newcastle remain the only major cities to have fluoride added to the drinking water in the UK. Of the 28 Strategic Health Authorities (in existence prior to the re-organization in 2006), only 10 had populations that benefit wholly or partly from water fluoridation (Table 3.1). This is largely owing to legislative problems arising from the Water Act (1985) and a combination of political, legal, geographical and financial factors. (See Figure 3.1 for a summary of events in water fluoridation).

One of the strengths of water fluoridation is that it can be cost effective. It may also result in reduced treatment costs. The U.S. Centers for Disease Control and Prevention (CDC) named water fluoridation as one of the 10 most important public health measures of the 20th Century (CDC 2000). It is important to remember, however, that since the implementation of water fluoridation schemes there have been changes not only in the availability of fluoride in dental products, notably dentifrices, but also in the prevalence in caries. The 50%-70% reductions in caries levels observed in Dean's studies in the United States continued at similar levels until the 1980's when it was observed that the DMFS scores in children living in fluoridated communities were only 18% lower than those in non-fluoridated communities (Brunelle and Carlos 1990). Both communities had demonstrated declines in caries prevalence. The difference between the communities was still significant at 18%, but it had also reduced. This effect has been largely attributed to the widespread use of fluoride dentifrices and the distribution of food and beverages prepared with fluoridated water into non-fluoridated communities (Horowitz 1996).

The pattern of caries prevalence has been similar in the UK. The large falls in caries levels observed in fluoridation schemes in Anglesey, Newcastle and the West Midlands in the 1960's and 1970's has been followed by falls in caries levels in both fluoridated and non-fluoridated communities. Overall, according to the Children's Dental Health surveys, the caries levels in children are falling in the UK (See Figure 3.2**.** There have long been health inequalities between social groups (See figure 3.3). However, despite these falls in overall caries levels it is apparent that inequalities in oral health have not reduced, but have widened between social classes (Watt and Sheiham 1999). It has been shown that water fluoridation may reduce the social class gradient between deprivation and caries experience by reducing the caries levels in more deprived areas compared to more affluent areas (Riley, Lennon et al. 1999). It has been shown that water fluoridation plus the use of fluoridated dentifrices alone is more effective than the use of fluoridated dentifrice alone (Whelton, Crowley et al. 2006). However, it is now becoming increasing difficult to investigate if water fluoridation has additional benefits to use of fluoridated dentifrice alone. This is owing to confounding factors such as accounting for total fluoride ingestion, deprivation, population migration and diet (Zohouri, Maguire et al. 2006; Maguire, Zohouri et al. 2007).

How is Water Fluoridated?

In the UK only two chemicals are permitted for use in the process of artificial water fluoridation, disodium hexafluorosilicate (Na_2SiF_6) and hexafluorosilicic acid (H_2SiF_6). This is stipulated in Section 87C(2) of the Water Act 2003, and the Code of Practice from the Drinking Water Inspectorate (HM Government 2003; DWI 2005). Both compounds must conform to strict European standards (BS EN Standards) that specify the purity and physical properties criteria that are required. In addition, these standards set down the testing methodology for sampling and analysis of the compounds and the labelling, transportation and storage instructions before the compounds are permitted for use in water fluoridation schemes.

The chemicals that are used in water fluoridation are often produced as by products in the phosphate fertilizer industry. The majority of fluoridation plants in the UK use the liquid hexafluorosilicic acid as the chemical of choice. The material is produced by the reaction of sulphuric acid with ground fluoride containing mineral. This produces hydrogen fluoride which is then purified through a process of washing, cooling, condensation and distillation. The hydrogen fluoride is then reacted with silica to produce ~ 40% concentrated hexafluorosilicic acid. Some manufacturers neutralize this acid with sodium carbonate to produce disodium hexafluorosilicate powder.

One argument of those opposed to water fluoridation is that it is possible that trace elements such as lead and arsenic are still present in these compounds from the natural minerals that the materials are sourced from. The levels of these contaminants that are permitted are strictly controlled by the Code of Practice on Technical Aspects on Fluoridation of Water Supplies 2005 (2005). In reality, some natural water has higher levels of these contaminants that need to be removed in order to comply with water quality regulations (HM Government 2000; HM Government 2001). The water from plants with or without fluoridation schemes must have contaminant levels below the levels outlined in the regulations.

Fluoride is added to the water supply during water treatment. Although the specific details may vary slightly between water treatment plants, the principles remain the same. Fluoride is delivered to the treatment plant by tanker and is stored in an acid resistant bulk storage tank. Sufficient water for 24 hours use is held in a “Day Tank” (See Figure 3.4). The correct quantity of hexafluorosilicic acid is actively pumped under careful monitoring at a rate proportional to the water flow rate into the Day Tank. The quantity of fluoride in the tank is constantly monitored at a sampling point distant to the injection pump but before the water is released into the distribution system. Safety features are integral to the system and an automatic shutdown occurs if there is an excess of fluoride or a malfunction in any part of the plant. A further series of tests takes place in the local distribution system and reports forwarded to the directors of public health. This is in addition to the testing stipulated under the water quality regulations (HM Government 2000; HM Government 2001). These procedures must include continuous fluoride monitoring linked to an alarm and automatic shutdown that runs within strict limits of fluoride levels and is subject to a minimum 24 hourly calibration. There are also requirements set out in the Water Supply (Water Quality) Regulations 2000 for the testing of consumer’s water supply for contaminants. This is set out for all water supplies, both fluoridated and non-fluoridated. The number and frequency of samples is determined by the size of the population served by a particular water plant.

There are also strict regulations set out for the transportation and storage of compounds used in water fluoridation. These include The Management of Health and Safety at Work Regulations 1999, Control of Substances Hazardous to Health Regulations 2002 (COSHH). The transportation of chemicals by tankers is covered by the Road Traffic (Carriage of Dangerous Substances in Road Tankers and Tank Containers) Regulations 1992. Chemicals stored on site in drums or other containers need to comply with the Chemicals (Hazard Information and Packaging for Supply) Regulations 2002.

The chemicals used for water fluoridation are not the only hazardous agents employed in water treatment; chlorine and ozone are used for disinfection purposes and require similar strict regulations to cover their use and storage. Many of the hazards of the use of fluorides in water often highlighted in the media are matched by similar hazards with other chemical that also require stringent safety procedures.

Natural vs. Artificial Water Supplies

Water is naturally fluoridated by the presence of calcium fluoride (also known as fluorspar). Calcium fluoride is relatively insoluble but when it dissolves it dissociates to produce fluoride ions:

$$CaF_2 \rightarrow Ca^{2+} + 2F^-$$

The compound that was added to water in the earliest days of artificial water fluoridation in the United States was sodium fluoride. This has now been largely replaced by the use of hexafluorosilicic acid and sodium hexafluorosilicate. These are the only two compounds that are permitted in the UK for use in artificial water fluoridation (HM Government 2003). When hexafluorosilicic acid is dissolved in water it hydrolyses and releases fluoride ions:

$$H_2SiF_6 + 4H_2O \leftrightarrow 6F^- + Si(OH)_4 + 6H^+$$

When sodium hexafluorosilicate is dissolved in water the overall reaction is:

$$Na_2SiF_6 + 4H_2O \leftrightarrow 6F^- + Si(OH)_4 + 2Na^+ + 4H^+$$

Irrespective of the chemical used for water fluoridation or the nature of fluoridation, natural or artificial, it has been shown that there is no difference in bioavailability of fluoride (K E Haneke and Carson 2001; Jackson, Harvey et al. 2002; Maguire, Zohouri et al. 2005; National Research Council 2006).

Summary

In this paper we have reviewed the history of water fluoridation and looked at its introduction as a dental public health measure. In the final paper in this series we will look at, the wider implications of systemic administration of fluoride, the arguments that advocate or oppose its use and the future of water fluoridation.

References

Abbott, A. L. (1966). "Fluoridation of Water Supplies." The Journal of the Royal Society for the Promotion of Health **86**(3): 181-187.

Arnold, F. A., Jr., H. T. Dean, et al. (2006). "Effect of fluoridated public water supplies on dental caries prevalence. 1956." Bull World Health Organ **84**(9): 761-4.

Backer Dirks, O., B. Houwink, et al. (1961). "The results of 6 1/2 years of artificial fluoridation of drinking water in the Netherlands. The Tiel-Culemborg experiment." Arch Oral Biol **5**: 284-300.

Black, G. V. (1916). "Mottled enamel. An endemic developmental imperfection of the teeth, heretofore unknown in the literature of dentistry." Dental Cosmos **58**: 129-156.

Brunelle, J. A. and J. P. Carlos (1990). "Recent trends in dental caries in U.S. children and the effect of water fluoridation." J Dent Res **69 Spec No**: 723-7; discussion 820-3.

Carmichael CL, Rugg-Gunn AJ, et al. (1989). "The relationship between fluoridation, social class and caries experience in 5 year old children in Newcastle and Northumberland in 1987." British Dental Journal **167**: 57-61.

Carmichael, C. L., A. D. French, et al. (1984). "The relationship between social class and caries experience in five-year-old children in Newcastle and Northumberland after twelve years' fluoridation." Community Dent Health **1**(1): 47-54.

Carmichael, C. L., A. J. Rugg-Gunn, et al. (1980). "The effect of fluoridation upon the relationship between caries experience and social class in 5-year-old children in Newcastle and Northumberland." Br Dent J **149**(6): 163-7.

CDC (2000). "From the Centers for Disease Control and Prevention. Achievements in public health, 1900-1999: fluoridation of drinking water to prevent dental caries." Jama **283**(10): 1283-6.

Churchill, H. V. (1931). "Occurrence of fluorides in some waters of the United States." J Ind Eng Chem. **23**: 996-98.

Dean, H. T. (1934). "Classification of mottled enamel diagnosis." J Am Dent Assoc **21**(1421-6).

Dean, H. T. (1938). "Endemic Fluorosis and its relation to dental caries." Public Health report **53**: 1443-1452.

Dean, H. T. (1939). "Mottled enamel in South Dakota." Public Health Rep **54**: 212-28.

Dean, H. T., F. A. Arnold, et al. (1942). "Domestic water and dental caries. V. Additional studies of the relation of fluoride domestic waters to dental caries experience in 4,425 white children aged 12-14 years of 13 cities in 4 states." Public Health Rep **57**: 1155-79.

Dean, H. T., F. A. Arnold, et al. (1950). "Studies on mass control of dental caries through fluoridation of the public water supply." Public Health Rep **65**: 1403-8.

Dean, H. T., P. Jay, et al. (1939). "Domestic water and dental caries. II. A study of 2,832 white children aged 12-14 years, of eight suburban Chicago communities, including L. acidophilus studies of 1,761 children." Public Health Rep **56**: 761-92.

Dean, H. T., P. Jay, et al. (1939). "Domestic water and dental caries, including certain epidemiological aspects of oral L. acidophilus." Public Health Rep **54**: 862-88.

DWI (2005). Drinking Water Inspectorate: Code of Practice on Technical Aspects of Fluoridation of Water Supplies 2005. London, DWI.

French, A. D., C. L. Carmichael, et al. (1984). "Fluoridation and dental caries experience in 5-year-old children in Newcastle and Northumberland in 1981." Br Dent J **156**(2): 54-7.

Groeneveld, A. (1985). "Longitudinal study of prevalence of enamel lesions in a fluoridated and non-fluoridated area." Community Dent Oral Epidemiol **13**(3): 159-63.

Groeneveld, A., A. A. Van Eck, et al. (1990). "Fluoride in caries prevention: is the effect pre- or post-eruptive?" J Dent Res **69 Spec No**: 751-5; discussion 820-3.

HM Government (2000). Water Supply (Water Quality) Regulations 2000. HMSO: London.

HM Government (2001). The Water Supply (Water Quality) (Amendment) Regulations 2001. HMSO: London.

HM Government (2003). Water Act 2003. HMSO: London.

HMSO (1962). Ministry of Health, Scottish Office & Ministry of Housing and Local Government (1962) The Conduct of the Fluoridation Studies and the Results Achieved after Five Years. (Reports on Public Health and Medical Subjects No.105). London, HMSO.

HMSO (1969). Department of Health and Social Security, Scottish Office,Welsh Office & Ministry of Housing and Local Government (1969) The Fluoridation Studies in the United Kingdom and the Results Achieved after Eleven Years (Reports on Public Health and Medical Subjects No.122) London, HMSO.

Horowitz, H. S. (1996). "The effectiveness of community water fluoridation in the United States." J Public Health Dent **56**(5 Spec No): 253-8.

Hulse, G., A. Kenrick, et al. (1995). "Welsh water should reinstate fluoridation on Anglesey." Br Dent J **178**(2): 46-7.

Jackson, D., P. M. James, et al. (1985). "Fluoridation in Anglesey 1983: a clinical study of dental caries." Br Dent J **158**(2): 45-9.

Jackson, D., P. M. James, et al. (1975). "Fluoridation in Anglesey. A clinical study." Br Dent J **138**(5): 165-71.

Jackson, P., P. Harvey, et al. (2002). Chemistry and Bioavailability Aspects of Fluorides in Drinking Water. Marlow, Buckinghamshire, WRc.

K E Haneke and B. L. Carson (2001). Toxicological Summary for Sodium Hexafluorosilicate [16893-85-9] and Fluorosilicic Acid [16961-83-4]. North Carolina, National Institute of Environmental Health Sciences.

Kalsbeek, H., G. W. Kwant, et al. (1993). "Caries experience of 15-year-old children in The Netherlands after discontinuation of water fluoridation." Caries Res **27**(3): 201-5.

Kwant GW, Houwink B, et al. (1973). "Artificial fluoridation of drinking water in the Netherlands. Results of the Tiel-Culembourg experiment after 161/2 years." Neth Dent J **80**: 6-27.

Maguire, A., F. V. Zohouri, et al. (2007). "Fluoride intake and urinary excretion in 6- to 7-year-old children living in optimally, sub-optimally and non-fluoridated areas." Community Dent Oral Epidemiol **35**(6): 479-88.

Maguire, A., F. V. Zohouri, et al. (2005). "Bioavailability of fluoride in drinking water: a human experimental study." J Dent Res **84**(11): 989-93.

McKay, F. S. (1928). "The relation of mottled enamel to caries." J Am Dent Assoc **15**: 1429-37.

Mitropoulos, C. M., M. A. Lennon, et al. (1988). "Differences in dental caries experience in 14-year-old children in fluoridated South Birmingham and in Bolton in 1987." Br Dent J **164**(11): 349-50.

Mullen, J. (2005). "History of water fluoridation." Br Dent J **199**(7 Suppl): 1-4.

Murray, J. J., P. H. Gordon, et al. (1984). "Dental caries and enamel opacities in 10-year-old children in Newcastle and Northumberland." Br Dent J **156**(7): 255-8.

Murray, J. J., A. J. Rugg-Gunn, et al. (1991). "In Fluorides in Caries Prevention.,Butterworth-Heinemann Ltd."

National Research Council (2006). Fluoride in Drinking Water. A Scientific Review of EPA's Standards, The National Acadamies Press.

Riley, J. C., M. A. Lennon, et al. (1999). "The effect of water fluoridation and social inequalities on dental caries in 5-year-old children." Int J Epidemiol **28**(2): 300-5.

Rugg-Gunn AJ, Carmichael CL, et al. (1977). "Fluoridation in Newcastle and Northumberland: a clinical study of 5-year-old children. ." British Dental Journal **142**: 359-402.

Rugg-Gunn, A. J., C. L. Carmichael, et al. (1988). "Effect of fluoridation and secular trend in caries in 5-year-old children living in Newcastle and Northumberland." Br Dent J **165**(10): 359-64.

Seaman, S., F. D. Thomas, et al. (1989). "Differences between caries levels in 5-year-old children from fluoridated Anglesey and non-fluoridated mainland Gwynedd in 1987." Community Dent Health **6**(3): 215-21.

Watt, R. and A. Sheiham (1999). "Inequalities in oral health: a review of the evidence and recommendations for action." Br Dent J **187**(1): 6-12.

Whelton, H., E. Crowley, et al. (2006). "Dental caries and enamel fluorosis among the fluoridated population in the Republic of Ireland and non fluoridated population in Northern Ireland in 2002." Community Dent Health **23**(1): 37-43.

Zohouri, F. V., A. Maguire, et al. (2006). "Sources of dietary fluoride intake in 6-7-year-old English children receiving optimally, sub-optimally, and non-fluoridated water." J Public Health Dent **66**(4): 227-34.

Table 3.1: Extent of Fluoridation in UK: SHA level prior to 2006 (taken from One in a Million, by kind permission of the British Fluoridation Society).

Strategic Health Authority	Total population	Population with fluoridated water supply	% of total population	Natural or adjusted
Bedfordshire & Hertfordshire	1,597,607	197,961	12%	Adjusted
Birmingham, Solihull & the Black Country	2,253,600	2,175,366	97%	Adjusted
Cheshire & Merseyside	2,342,941	136,700	6%	Adjusted
Co Durham & Tees Valley	1,130,907	220,867	20%	Natural & Adjusted
Cumbria & Lancashire	1,900,226	120,000	6%	Adjusted
North & East Yorkshire & Northern Lincolnshire	1,603,635	135,546	8%	Adjusted
Northumberland, Tyne & Wear	1,381,728	647,863	47%	Adjusted
Shropshire & Staffordshire	1,482,537	518,170	35%	Natural & Adjusted
Trent	2,580,579	536,276	21%	Adjusted
West Midlands South	1,524,100	940,212	62%	Adjusted
Totals		**5,628,961**		

Figure 3.1. Timeline of Water Fluoridation

1901 – Frederick McKay notices "Colorado Brown Stain" on patient's teeth

1916 – G V Black reports on Mottled enamel

1925 – Ainsworth observes less caries in patients with mottled teeth

1931 – Churchill reports on link between fluoride in water and mottled teeth

1934 – Dean develops an index for measuring mottling, now renamed fluorosis

1939 – H Trendley Dean and McKay report reduced caries rates in patients exposed to water causing mottled enamel

1942 – Dean compiles fluorosis prevalence data for most of the USA

1944 – Weaver reports less caries in fluoridated South Shields vs non-fluoridated North Shields

1945 – Grand Rapids becomes first city to artificially fluoridate water supply

1950 – Dean reports on the benefits of water fluoridation

1953 – Tiel Culemborg fluoridation trial commences in the Netherlands

1955 – Anglesey, Watford and Kilmarnock commence water fluoridation trial

1955 – Proctor and Gamble launch first fluoride toothpaste, Crest

1962 – Kilmarnock withdraws water fluoridation

1964 – Fluoridation scheme commences in the West Midlands

1968 – Fluoridation scheme commences in Newcastle

1971 – Tiel Culemborg experiment ends in Netherlands

1983 – McColl v Strathclyde Regional Council, outlaws water fluoridation in Scotland

1985 – Water Act, provides privatized water companies an opportunity to veto water fluoridation

1992 – Fluoridation scheme in Anglesey ends

2000 – York University Centre for Research Dissemination publishes review on water fluoridation

2002 – Medical Research Council publishes "Water Fluoridation and Health"

2003 – Water Act removes barrier preventing new water fluoridation schemes

2008 – Rt Hon. Alan Johnson announces intention to promote water fluoridation to areas in need

2009 – South Central SHA holds public consultation for water fluoridation in Southampton

Figure 3.2. Percentage of children with obvious decay experience in permanent teeth Data from Children's Dental Health in the UK 2003

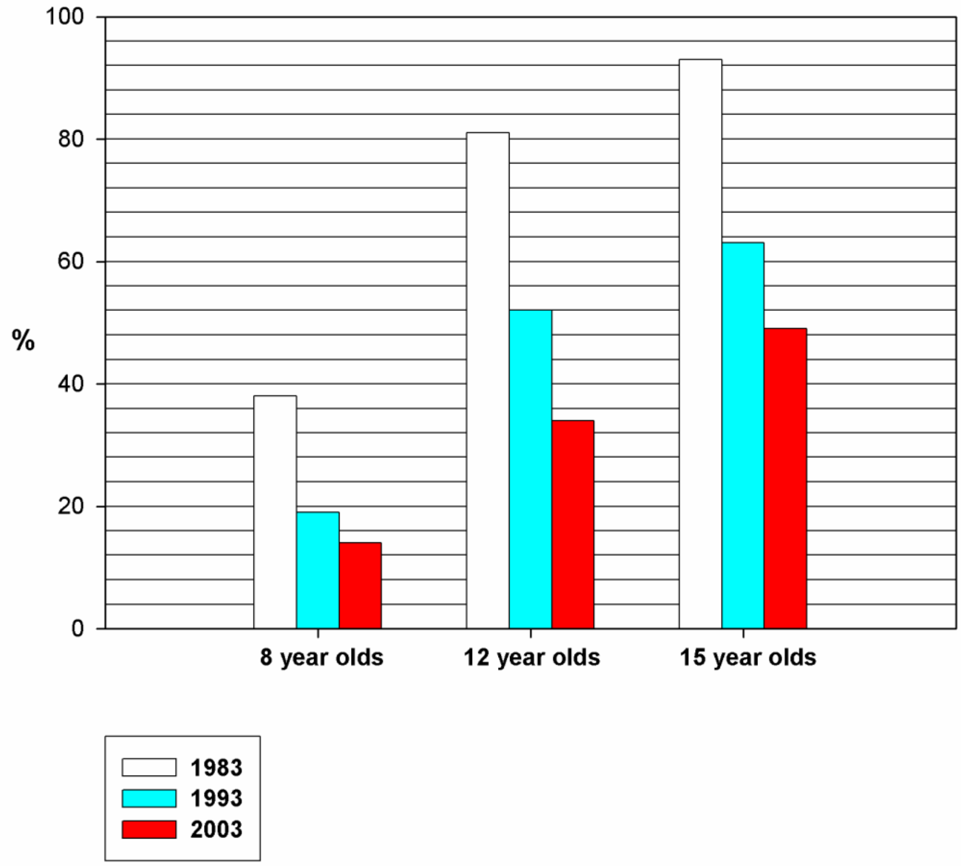


Figure 3.3. Social class inequalities in oral health of 5-year-olds in UK

Source: National Children's Dental Health Surveys 1973 - 1993

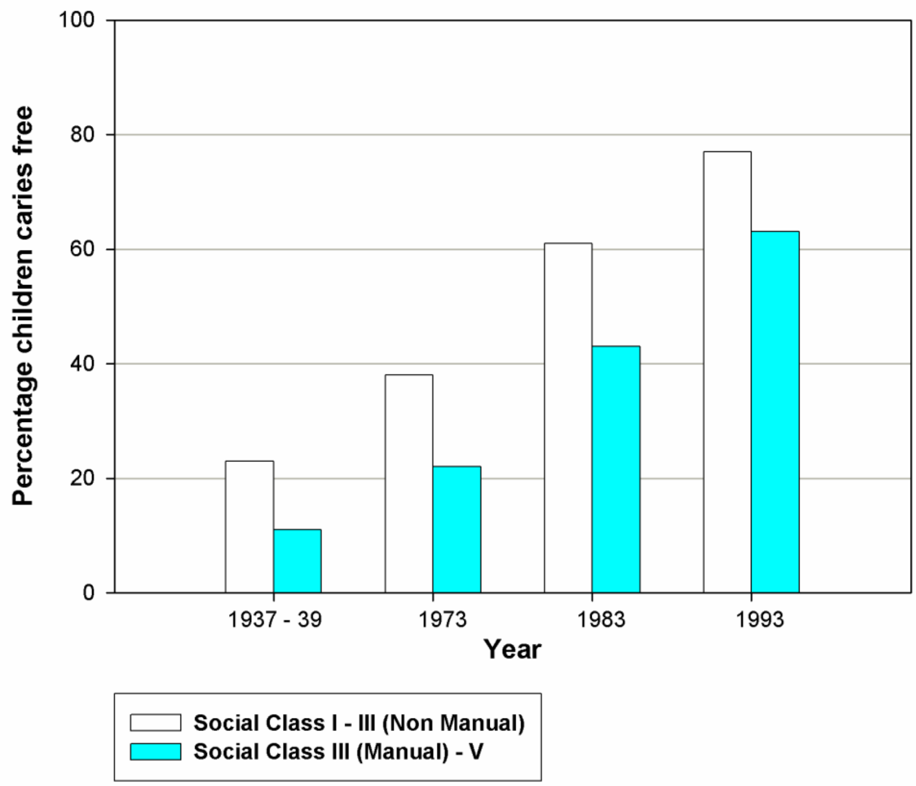


Figure 3.4. Water treatment plant storage facilities. Images provided courtesy of Northumbria Water Plc.

Figure 3.4.1 Storage area H_2SiF_6 water treatment works

Figures 3.4.2 and 3.4.3 Storage tanks for H_2SiF_6 and safety monitoring equipment

Figure 3.4.3

Chapter 4

Literature Review: Dental Update Series Part Three, the Water Fluoridation Debate

Published Dental Update December 2010.

McGrady MG, Ellwood RP, Pretty IA. The Water Fluoridation Debate. Dental Update 2011; 38: 12-22

Dental Public Health

Part Three: The Water Fluoridation Debate

M.G. McGrady*

BDS, PG Dip

StR/Honorary Lecturer in Dental Public Health, the University Of Manchester

R. P. Ellwood

BDS, MDS, MSc, PhD, FFPH

Professor of Dental Diagnostic Science, Dental Health Unit, the University of Manchester

I.A. Pretty

BDS(Hons), MSc, PhD, MFDSRCS (Ed)

Senior Lecturer in Dental Public Health, the University of Manchester

***Corresponding Author:**

Michael G McGrady

Room 1.030 Coupland 3 Building

School of Dentistry

The University of Manchester

Higher Cambridge Street

Manchester

M13 9PL

The Water Fluoridation Debate

Abstract

Water fluoridation schemes have been employed for over 50 years. It has been a source of continuous debate between those who advocate its use as a public health measure and those who oppose it. There have been no new fluoridation schemes in the UK for nearly 30 years owing to principally legislative, but also geographic, financial, and political reasons. However, in early 2008 the UK Secretary of State for Health promoted the use of water fluoridation schemes for areas in England with the highest rates of decay. This article aims to discuss the arguments surrounding water fluoridation and its continued relevance as a public health measure.

Part Three

Clinical Relevance

This article aims to provide an update for general practitioners for the back ground and the current status of the water fluoridation debate and to enable them to answer non-clinical questions raised by patients.

Paper 3 – The Water Fluoridation Debate

Introduction

The first two articles in this series reviewed the history of fluorides in dentistry and of water fluoridation and the background for the evidence base that resulted in water fluoridation schemes. In this final article we will examine the legal history and the current legislative status. We will discuss the arguments and evidence for those who advocate water fluoridation and those who oppose it as a dental public health measure. We will expand on the issues surrounding risk benefit for water fluoridation beyond dental fluorosis, and how they have altered with time. We will also discuss the continued relevance of water fluoridation as a contemporary public health measure.

Legal History and the New Legislation

Legislation of the water industry in the UK to protect the public and regulate the safety of water supplies has been in place for over 100 years. It appeared as a response to an outbreak of cholera from a public water supply (Lowry and Evans 1999). The majority of water companies were for a long time in the public sector and were controlled at a governmental or local authority level. It was during this period of public ownership that the fluoridation schemes in the UK were introduced. On the basis that it was in the public's best interest the water companies, both private and state owned, were persuaded to fluoridate water supplies. The companies were to fluoridate the water supply under a non-profit agreement whereby all appropriate costs were met by the state. However, a series of events in the 1980's changed the picture of water fluoridation with far reaching effects. The first of these events was a ruling given on a case before the Scottish judiciary.

Events began in 1978 when Strathclyde Regional Council, as the statutory water authority for the area agreed to cooperate with the local Health Boards to add fluoride to the water supply. In 1979, an elderly citizen of Glasgow, Mrs Catherine McColl, applied for an interdict to restrain Strathclyde Council from implementing water fluoridation. This was granted pending court hearings. Mrs McColl's grounds for complaint were that water fluoridation was 1) *ultra vires*[1] Strathclyde Council, 2) a nuisance, as fluoride was a known toxic substance harmful to consumers of fluoridated water, 3) an infringement of the duty of the water authority to provide consumers with wholesome water for domestic purposes, and 4) an infringement of the Medicines Act, 1968 as by implementing water fluoridation (without a product license) Strathclyde Council would be supplying a medicinal product for a medicinal purpose.

The plaintiff was granted legal aid, Lord Jauncey was appointed as the judge. As the first and last grounds for complaint were matters of law, no evidence was heard on these points. However, the other two points required the presentation of evidence. The hearings began on the 23rd September 1980 in the Court of Session, Edinburgh. What followed made the case famous not only for its subject matter, but for the cost and the length of the proceedings – it ran until 26th July 1982 (the Court having sat for a staggering 201 days – the longest case in Scottish legal history). Lord Jauncey took almost another year to consider the 21,000 pages of written evidence that had been amassed. When a verdict was finally reached on the 23rd June 1983, the judge sustained the Petitioner's plea in law that fluoridation for the purpose of reducing the incidence of dental caries was *ultra vires* the respondent, and the interdict was granted on this point and on this point alone. All her other pleas were rejected.

The outcome of the case was viewed as a moral victory for the anti-fluoridation lobby, despite the fact that all pleas pertaining to the efficacy and safety of water fluoridation were lost. Lord Jauncey stated that an "*...individual's right to choose how to care for his own body should only be encroached upon by statutory provisions in clear and unambiguous language."* (1983). This should have been interpreted as a legal, not moral judgement. However, the message was that the law needed to be clarified where there was an intention for the addition of fluorides to drinking water.

The ramifications of this ruling meant that existing fluoridation schemes, at least under the view of Scottish law, were unlawful. The Conservative government at the time were keen

[1] *Ultra vires* – meaning beyond the power of. In this case, that the implementation of water fluoridation was beyond the legal powers of Strathclyde Council.

to pursue the option of water fluoridation as a cost effective means of addressing dental caries. The 1985 Water (Fluoridation) Bill (HM Government 1985) was seen as an attempt to address the legal short comings highlighted in Lord Jauncey's verdict. The Bill was seen to be a mechanism for the introduction of new water fluoridation schemes and set out clear roles and responsibilities for health authorities, water companies and the Secretary of State. However, there was another significant change in circumstance for water companies that occurred at this time – the privatization of water companies. In order not to jeopardize the privatization programme, a decision was taken to retain the right of the water companies to veto new water fluoridation schemes, a veto that was less significant when the water companies were in the public sector. This was seen as a solution whereby the newly formed private companies would not have restrictions placed on their operating practices by the public sector.

When the Act (HM Government 1985) was passed the Government could be seen as being supportive of the extension of water fluoridation schemes, whilst having made what could be interpreted as a conscious decision not to make the process easier. The Act included the section:

> *"If requested to do so by a relevant authority, a water undertaker* ***may*** *enter into arrangements with the relevant authority to increase the fluoride content of the water supplied by that undertaker to premises specified in the arrangements".*

Unsurprisingly, as a result of this change in legislation and the wording that provided water companies a veto, there were no new fluoridation schemes implemented. As an aside, it must be stressed that even prior to these events, there were still overwhelming obstacles to overcome when it came to water fluoridation. The NHS Reorganisation Act of 1973 (HM Government 1973) resulted in massive changes within the NHS. The NHS now encompassed the running of hospitals and community and preventive services, which included the transfer of the responsibility for water fluoridation from local government. Plans for water fluoridation were easily pigeon-holed when the broader picture of health care provision was considered. Added to this was increasing geographical and political pressure from within water companies, local government and even some Area Health

Authorities (Castle 1987). The struggle for the West Midlands to extend the existing fluoridation scheme in the late 1970's and early 1980's is documented by Paul Castle in "The Politics of Fluoridation" (Castle 1987).

The first true test of the revised legislation of the Water (Fluoridation) Act, 1985 and the Water Industry Act, 1991 (HM Government 1991) that followed came about by a judicial review raised by Newcastle and North Tyneside Health Authority in 1998 following a refusal to a request from the Health Authority to Northumbrian Water to extend an existing water fluoridation scheme. The judicial review aimed to clarify the responsibility of the water company in the decision making process. The Health Authority contested that Northumbrian Water had acted unlawfully by refusing their request and that the reasoning provided was illogical. The water company countered that they had the absolute right to veto such decisions and that post privatization they had a right to protect shareholders and under the current law no other considerations (even public health) could take precedence. The presiding judge, Mr Justice Collins concluded that as regrettable as it was, the water company had the absolute right under the existing legislation to refuse such a reasonable request.

As a consequence of the legislation failing to deliver what had been intended. A white paper was commissioned in 1998 on public health. This included details that described the 1985 Water (Fluoridation) Act as "flawed legislation". As a result, in a resolution passed by a free vote, Parliament passed new legislation in 2003 (HM Government 2003). Section 58 of the Water Act 2003 states:

> *"If requested to do so by a relevant authority, a water undertaker* ***shall*** *enter into arrangements with the relevant authority to increase the fluoride content of the water supplied by that undertaker to premises specified in the arrangements".*

The replacement of the word *"may"* from the earlier Act by the word *"shall"* was the critically important change. Section 58 also put new emphasis on the requirement for public consultation before any new fluoridation scheme is requested (or an existing scheme terminated). Regulations are to be drawn up on consultation and assessment of public opinion. Water companies have always been indemnified by the Government in respect of liabilities that they may incur in respect of fluoridation, and the new Act provided for Regulations to be drawn up governing future indemnities. The new legislation has requirements for monitoring of the health impact not only of new schemes but also existing water fluoridation schemes. It remains to be seen how successful the most recent changes of legislation have been. Attention is drawn to events occurring in South Central SHA where the outcome of a public inquiry was the decision by the SHA to initiate a water fluoridation scheme in Southampton pending a judicial review. It should also be noted that the recent White Paper on NHS reform will result in the abolishment of Primary Care Trusts and Strategic Health Authorities. This may have an impact on the South Central SHA review and any future proposed fluoridation schemes

The Objections and the Evidence – MRC and York

Those who oppose water fluoridation have a loud voice. A simple internet search will reveal a large number of groups against the use of fluoride. The websites are filled with articles and reviews that purport the dangers of fluoride, often with support from individuals described as eminent scientists and institutions. The various groups do not necessarily agree with one another, but they share some arguments against water fluoridation, including several key issues. Quite often, the different groups are formed by the same small group of individuals. The arguments against water fluoridation are wide and varied. It is beyond the scope of this article to discuss each and every objection to water fluoridation. The main themes of the objections include, but are not limited to:

1] the fact that fluorine and fluoride compounds are toxic and may act as a cumulative poison (Connett P; Boivin, Chavassieux et al. 1986; Groves 2001) ,

2] that fluoride is linked to increased prevalence of cancers, bone disorders, mental disorders and is a danger to certain “at risk” groups such as renal patients (Connett P; Juncos and Donadio 1972; Groves 2001).

3] Opponents also cite the chemicals used in water fluoridation labelling them as hazardous waste products that would have to be disposed of under strict and expensive regimes if they were not simply dumped in to our water supply (Connett P; Groves 2001).

4] There is a claim that compounds that are used in artificial fluoridation schemes do not have the same properties as calcium fluoride found in naturally fluoridated water (Connett

P; Groves 2001). 5] Some will argue that fluoridation simply does not work and that caries levels have fallen by similar degrees in both fluoridated and non-fluoridated communities (Connett P; Groves 2001), and 6] in some cases that caries levels are increased in areas with high levels of fluoride in the water (Teotia and Teotia 1994; Groves 2001). All of these points can be argued, but it should be stated that it is far more difficult to prove scientifically that something “will not happen”, such as developing fluorosis on exposure to fluoride than demonstrating that a risk of fluorosis exists when exposed to fluoride. Taking each in turn:

The points highlighted in 1 and 2 above can be addressed by the fact that despite the fact that water fluoridation schemes have been in place for over 50 years no major study or review has unequivocally concluded that water fluoridation at an optimal level has resulted in an increase in the prevalence of any of the conditions cited (Knox 1985; NHS-CRD 2000; MRC 2002; National Research Council 2006; Yeung 2008). However, there remains the caveat that in many areas further research is required to strengthen the evidence base.

Any discussion regarding point 3 above is a moot point. The chemicals used in water fluoridation schemes are produced during the manufacturing processes involved in the fertiliser industry. However, simply labelling them as waste products is not entirely true. Co-products or by-products could be a more accurate description. The chemicals are hazardous at the concentration levels at which they are produced, transported and stored, but not at the diluted levels found in the water supply. It has been suggested by the anti-fluoridation lobby that the safety of fluorosilicates has never been investigated (Connett P; Groves 2001). However, a report was commissioned by the National Institute of Sciences to address this issue (K E Haneke and Carson 2001) and concluded that at the recommended levels fluorosilicates were safe as agents in water fluoridation. An independent report by the Water Research Centre (WRc) looked at the chemistry and safety of fluorides in drinking water and it also concluded that the water fluoride concentration was safe at the optimum levels (Jackson, Harvey et al. 2002).Irrespective of the semantics, the chemicals involved in water fluoridation must comply with stringent regulations (as previously discussed).

The issue to be taken up with point 4 is that of the bioavailability of fluoride compounds in water supplies. A study to examine the bioavailability of fluoride between water with naturally occurring fluoride and artificial fluoridation found that if any differences did exist in the bioavailability of the fluoride whether it was natural or artificial, present in either hard or soft water, they would be irrelevant when compared to subject variation (Maguire, Zohouri et al. 2005). This study was criticized for having a relatively small sample size and for the conclusions that it raised (Cheng, Chalmers et al. 2007). However, the results of this study are consistent with those found in other reports that there is no difference in the bioavailability of natural and artificial fluoride in water (Urbansky and Schock 2000; K E Haneke and Carson 2001; Jackson, Harvey et al. 2002; National Research Council 2006). The authors subsequently responded to criticism of the paper (Sheldon, Holgate et al. 2008).

The criticisms raised in point 5 are rather more interesting to analyze. It is true that the initial benefits that were seen when water fluoridation schemes were implemented appear to have diminished with time. This is largely owing to the advent of freely available alternate sources of fluoride, particularly fluoridated toothpastes.

There has been a steady decline in caries prevalence in Europe in both fluoridated and non-fluoridated communities over the past few decades according to figures published by the World Health Organisation (See Figure 4.1). This has resulted in smaller differences between the two groups. Despite studies showing the reduction in caries in fluoridated communities, and an additional effect of water fluoridation plus fluoridated toothpaste use (Whelton, Crowley et al. 2006) it is becoming increasingly difficult to control such studies for confounding factors such as fluoride from other sources, diet, socio-economic status and population migration. Furthermore, consideration must be given to the "halo effect" resulting from diffusion of foodstuffs and beverages prepared in fluoridated areas being consumed in non-fluoridated areas (Griffin, Gooch et al. 2001). The fundamental question remains to be answered – does water fluoridation continue to have a benefit above the use of fluoridated dentifrices alone?

By looking at the extreme situation raised in point 6, some of the protagonists in the anti-fluoridation lobby have been accused of less than honest behaviour, misquoting or misrepresenting conclusions from the literature and have been reported as overstating their point where negative outcomes have been reported (Cheng, Chalmers et al. 2007). There have been occasions where data in the literature have been misquoted or misrepresented. One case in point involved a large 400,000 subject survey in India looking at caries, high levels of fluoride in water and calcium nutrition (Teotia and Teotia 1994). The anti fluoridation lobby not only highlighted the severity of fluorosis (a point that was obvious, as it is endemic in this region), but also reported that the prevalence of dental caries was higher in a population that was fluoridated than a non-fluoridated population. The antifluoridation lobby stated that fluoride was not only dangerous but was ineffective at reducing caries (Groves 2001). Closer examination of the original paper reveals that this fact taken in isolation was true. However, what the anti-fluoridation lobby failed to add was that in the population with endemic fluorosis where the caries rates were higher, the authors reported that there was also widespread calcium deficiency associated with reduced calcium intake and the higher caries was linked not only the deficiency of calcium but also the combination of this with excessive fluoride. The paper concluded that caries control in this region should be modelled on water fluoride levels <0.5ppm and adequate calcium nutrition (>1g/day).

Another example cited as demonstrating an increase in caries levels with water fluoridation is a study performed by Ekanayake in Sri Lanka (Ekanayake and van der Hoek 2002) who examined the prevalence of caries and enamel defects in populations drinking differing concentrations of fluoride in drinking water. The study did find that there was an increase in caries prevalence linked to the severity of diffuse enamel opacities, and that there was an increased risk to caries in those with severe enamel defects when the water fluoride concentration was >0.7 mg/l. The conclusion was that the appropriate level of water fluoride concentration should be 0.3mg/l in this region. Ekanayake in a later paper stated that there was a need to identify factors other than water fluoride concentration contributing to severity of enamel defects (Ekanayake and van der Hoek 2003). A similar conclusion was found by Grobler (Grobleri, Louw et al. 2001) in South Africa. Although once again the study is cited for an increase in caries where there is fluoride in the water, the conclusion of the study is that there was lower caries experience in a community with low water fluoride levels. None of the studies cited by the anti-fluoridation lobby as showing higher caries (with water fluoride) included areas where there was an area with no water fluoride as a control. The data does show an increased prevalence of caries where there were excesses of fluoride, but where the fluoride level is considered optimal for the region there are decreases in caries experience. It should also be stated that nobody advocates water fluoride concentrations at such high levels as a means of preventing caries.

Individuals within the anti-fluoridation lobby have attracted attention. In his summary of the case Mrs Catherine McColl v Strathclyde Regional Council, Lord Jauncey criticized the principal witness for the plaintiff. In his summary Lord Jauncey commented that the witness…

> "*… who played so prominent a part in this case is undoubtedly a propagandist as well as a scientist…but I was driven to the conclusion that he not infrequently allowed his hostility to fluoridation to obscure his scientific judgement… …displayed great ingenuity and a very fertile mind during his evidence".*

This was a measured opinion on an individual who was a prominent figure in the anti-fluoridation lobby. Nevertheless, those who oppose fluoridation are often dismissed by some in the scientific community as scaremongers, and "quacks" (Lowry 2000).

Opponents of fluoridation state that the addition of fluoride compounds into community drinking water takes away individual choice and amounts to mass medication. Such opposition has a loud and influential voice often with the support of politicians and political parties (Fitz-Gibbon 2003). The arguments of freedom of choice and adopting a position whereby water fluoridation is mass medication are certainly legitimate points worthy of debate. Every opponent of water fluoridation cites that it is a violation of the individuals rights (Connett P; Coggon and Cooper 1999; Groves 2001; Cross and Carton 2003; Cheng, Chalmers et al. 2007). These rights are judged to be laid down in the European Convention for the Protection of Human Rights and Dignity of the Human Being with Regard to the Application of Biology and Medicine; Convention of Human rights and Biomedicine. The British Government has not yet signed to the whole of this convention. However, under the

European Charter of Fundamental rights, there is a possibility that that the veto may be removed. Of course, this would only hold true if water fluoridation were judged to be a medicinal product. Those who oppose fluoridation claim that it amounts to mass medication without consent, without correct dosage and without products tested to pharmaceutical standards. At present, the regulatory body, The Medicines and Healthcare products Regulatory Agency (MHRA) are not responsible for regulating drinking water. This falls within the remit of the Drinking Water Inspectorate through The Water Supply (Water Quality) Regulations 2000 (HM Government 2000), not the Medicines Act (1968). This provides a subject of great debate as the regulatory status of water fluoridation and the arguments of the opponents form the cornerstone to the legality of water fluoridation within the UK.

There is an important distinction that must be made between the scientific debate of the safety and efficacy of water fluoridation and the moral implications of such public health policies. If we were to assume that water fluoridation was safe and effective, then there still remains a moral question relating to beneficence and autonomy (Cohen and Locker 2001). Does the overall benefit to a population outweigh the right of an individual to choose? Lord Avebury adopted the position that the civil liberties and rights that are referred to by those who oppose water fluoridation do not give an individual the *"right to dictate the chemical composition of the water supply"* (Avebury 1984).

The compulsory wearing of car seatbelts, the fortification of foods, prenatal blood tests for genetic conditions and vaccination programmes are examples whereby individual rights can be judged to have been removed in what are accepted public health or safety policies. Some may argue that there is a difference between preventing communicable disease and preventing dental caries. However, the end goal is the same – an attempt to reach those at risk and the reduction in treatment costs that could have arisen. This is especially true for a public funded health care system such as the NHS. This is a brutal point, but unfortunately a relevant one when we live a society of fixed budgets for health care provision. Is it not just as unethical to ignore the potential for prevention, cost effectiveness and the reinvestment of monies where it is needed most? There appears to be no escape from this position of beneficence and autonomy, even if there were no risks associated with fluoridation.

Political opposition and the subject of personal choice are not the only obstacles for the implementation of water fluoridation. Geographical limitations may occur such as conflict between the boundaries of water companies and those of health authorities can create problems where one health authority requests fluoridation, but water treatment plants and supply overlap into another health authority not requesting fluoridation. If the supply of water to a region is fragmented and divided between numerous water treatment plants, inadequate infrastructure may reduce the cost effectiveness of implementing water fluoridation. Under these circumstances it is often advisable to seek alternative public health policies. For example, France has over 20,000 separate public water sources. This would make water fluoridation technically difficult to implement. Under these circumstances it is more appropriate to seek alternative means of fluoride delivery. In Europe, for example, there is extensive use of fluoridated salt.

There have been attempts to address the issues surrounding water fluoridation. The Department of Health (DoH) commissioned a systematic review on water fluoridation that was published in September 2000. This report was carried out by the Centre for Reviews and Dissemination, University of York and became known in the dental research community as the York Report (NHS-CRD 2000). The York Report was commissioned by the Chief Medical Officer to *'carry out an up to date expert scientific review of fluoride and health'* (DOH 1999). It was hoped that it would be the final word on water fluoridation. There were five key objectives of the review:

1. To examine the effects of fluoridation of water on the incidence of caries
2. To examine any effects of water fluoridation (if any) over and above those offered by alternative interventions and strategies
3. To examine if water fluoridation results in caries reduction across social groups and geographical locations, bringing equality
4. To examine if negative effects of water fluoridation exist

5. To examine if there are differences in the effects of natural and artificial water fluoridation

The report concluded that despite the fact that current research on fluoridation supported the benefits of water fluoridation; certain aspects within the evidence base were not acceptable and the York Report commented that future research should address these issues. The report also stated that the evidence base did not permit confidence in statements relating to potential harm or the impact on social inequalities. The report also concluded that future research should be "*considered along with the ethical, environmental, ecological, costs and legal issues that surround any decisions about water fluoridation*".

The report was met with mixed reaction. Both sides of the fluoridation debate criticized the report's contents and conclusions. Those who advocated fluoridation were disappointed that vast amounts of evidence illustrating the benefits of water fluoridation were omitted because the scientific standards of the day did not meet the strict standards required of more contemporary work. However, they were pleased with the report's conclusions that there was a clear benefit on caries levels. Opponents of fluoridation were disappointed that research was omitted from the review owing to the inclusion criteria set out for the review (Groves 2001). Data from reviews and commentaries were excluded, as were data from animal studies. They were also disappointed that the review looked at the effects of artificial water fluoridation and not fluorides from other sources. There was also concern that there had been no investigation of fluoride absorbed through the skin. The York Report failed to deliver the "knock-out punch" that both sides had been hoping for.

Following the York report, an Medical Research Council (MRC) publication; Water Fluoridation & Health (MRC 2002) also issued guidance on the research shortfalls in fluoride research and again recommended that this be a priority area for research in the future. The report also highlighted the need to examine the total fluoride exposure of individuals owing to the fact that potential exposure has increased as more dental health care products contain fluoride (Chowdhury, Brown et al. 1990; Hinds and Gregory 1995; Levy and Guha-Chowdhury 1999). Furthermore, the report recommended research into possible differences in fluoride uptake from naturally fluoridated water and artificially fluoridated water and to determine the impact of the level of water hardness on the bioavailability of fluoride.

The MRC also recommended that fluoride exposure in children should be examined to identify the impact of water fluoridation on the reduction in caries against a background of wider fluoride exposure from alternative sources, especially toothpaste. Greater knowledge is needed on how the effects of water fluoridation vary with social class, a link between dental caries prevalence and socio-economic status has been generally accepted (Rugg-Gunn AJ, Carmichael CL et al. 1977; Hinds and Gregory 1995). The majority of the literature to date suggests that water fluoridation may reduce dental caries inequalities between high and low socio-economic groups (Carmichael CL, Rugg-Gunn AJ et al. 1989). The MRC report recommended that research focused on appropriate measures of social inequalities related to water fluoridation, dental caries and fluorosis, taking into account factors such as use of other fluoridated products such as toothpaste and dietary sugar ingestion.

Although the majority of research has concentrated on children, future research should not ignore the effects of fluoridation on dental health in adults in addition to possible health outcomes (other than dental health) related to water fluoridation. The risk of hip fracture is the most important in public health terms. Early evidence on this suggests no effect, but is not conclusive (Hillier, Cooper et al. 2000), although a more recent study concludes that long term exposure to fluoride in drinking water did not increase the risk of fracture (Phipps, Orwoll et al. 2000). Similarly, available evidence of the impact of fluoridation on other bone disorders is not unequivocal owing to paucity of available data.

Another issue raised by the MRC is the possible role of fluoride and fluoridation on cancer incidence. Although the MRC stated that the evidence suggests no link between water fluoridation and either cancer in general or any specific cancer type (including osteosarcoma, primary bone cancer), an updated analysis of UK data on fluoridation and cancer rates is recommended in the report. This aspect will be covered by the implementation of a surveillance programme.

In the United States the Environmental Protection Agency (EPA) is responsible under the Safe Drinking Water Act to set and monitor the maximum exposure levels for contaminants in public water supplies. The remit of the report was not to investigate the safety of water fluoridation, but to examine fluoride at levels where it would be considered as a contaminant. The standards include the maximum contaminant level goal (MCLG), the maximum contaminant level (MCL) and the secondary maximum contaminant level (SMCL). The MCLG is set at level at which no adverse health effects can be expected to occur with "adequate" margins of safety. The enforceable standard is the MCL and is set as close to the MCLG as practicably possible. The SMCL is set by the EPA in circumstances of managing aesthetic, cosmetic or technical effects. Fluoride is one of the contaminants regulated by the EPA. Periodically, the EPA is required to review these standards. In 1986, the EPA set an MCLG and MCL for fluoride of 4mg/l and a SMCL of 2mg/l. It must be stressed that the EPA's work on this matter is not a means of assessing the safety or efficacy of water fluoridation in the reduction of dental caries, those standards were set for that purpose by the U.S. Public Health Service at a range of 0.7 – 1.2mg/l. The EPA's remit is to provide guidance on maximum allowable concentrations in drinking water from natural sources and artificial sources in order to prevent adverse or toxic effects that could result from exposure to fluoride.

The National Research Council (NRC) published the latest review of the EPA's standards in 2006 (National Research Council 2006). The NRC examined the evidence (including animal model data that was excluded from the remit of the York Report) covering fluoride exposure, dental effects, musculoskeletal effects, reproductive and developmental effects, neurotoxicity, endocrine effects, genotoxicity and carcinogenicity. The report was a comprehensive examination of the evidence available.

In summary, the NRC did find that there were some groups whose fluoride intake would be higher from water than most of the population e.g. athletes, outdoor workers and diabetics. The committee also concluded that severe enamel fluorosis could be classed as being more than merely cosmetically unacceptable. The balance of evidence across all of the areas investigated suggested further research in these fields was necessary and in light of this the MCLG of 4mg/l fluoride in drinking water should be lowered. The committee did not comment on the safety of water fluoride levels set for the purpose of preventing dental caries. However, this has not prevented some bodies such as the National Pure Water Association from citing the results from the NRC Report as evidence that water fluoridation is not safe. To suggest that because more evidence is needed to assess a MCLG of 4mg/l fluoride, that a level of 1mg/l (1ppm) fluoride is therefore unsafe is a little overcautious, and perhaps a misrepresentation of the conclusions of the NRC.

What is the Way Forward for Water Fluoridation?

The obvious statement to make would be that the opposing sides in the fluoridation debate need to find common ground. This may not be as difficult as it sounds. There are concessions that can be made by both sides. The common goal is the welfare of the patient, whether that is taken at an individual or population level. The ethical arguments of each side should be considered as fairly as those from the opposing side. Dentists could, and should, be better informed of the uses and abuses of fluoride. Their education on fluoride should be more comprehensive at undergraduate level and continue through to postgraduate level encompassing current evidence and the development of standard practices to maximize benefit and minimize risk, particularly in vulnerable groups.

Scientists and researchers, whether they are for or against fluoridation, should not allow their own feelings to overwhelm their work and thus prevent it from becoming propaganda that can be easily dismissed. Instead, research should continue to be evidence driven and peer reviewed, not merely an opinion. Science should not be simply dismissed if a conclusion differs from the norm, but challenged with reasoned and just argument not sound bites and propaganda designed to frighten or patronize the public.

Researchers need to address the issues raised by such reviews as the York Report, the MRC Report and The NRC Report. There is no denial that the evidence base needs to be improved and the legal position as to whether or not it amounts to medication clarified. If it is to continue and expand we need to provide evidence that water fluoridation continues to be effective above the use of fluoridated dentifrices alone, using methodologies that minimize bias and are more objective than traditional subjective indices. Techniques and technologies are available and continue to be developed to measure and quantify dental caries and enamel fluorosis (de Josselin de Jong, Sundstrom et al. 1995; Amaechi and Higham 2002; Berg 2006; Pretty 2006; Zandona and Zero 2006; Ismail, Sohn et al. 2007; Ricketts, Ekstrand et al. 2007).The effects of a changing society, with its changing social norms, diet and changing demographic and socioeconomic status need to be accounted for when looking at prevalence levels of caries and fluorosis (Carmichael CL, Rugg-Gunn AJ et al. 1989; Provart and Carmichael 1995; Tickle 2002; Ellwood, Davies et al. 2004; Jain, Shankar et al. 2007). Notwithstanding the necessity to obtain sufficient evidence for the safety and efficacy of water fluoridation, we also need to continue to look for alternative solutions. Not only if it is deemed unsuitable, but for areas where it is impractical to implement.

It is also necessary to examine the changing patterns of dental caries, how we record and report the findings of research and how we use the data to commission health care provision and targeted or focussed delivery of fluoride. Despite the fact that caries levels in the UK are falling as a whole, this cannot be said of individual groups whether in particular age groups, geographical areas, or differing social classes. The Children's Dental Health survey 2003 did demonstrate an overall fall in caries levels. However, the fall in levels for 5 and 8 year olds failed to demonstrate significant improvements (See Figure 4.2)**.** It should be stated that the 2003 survey included visual dentine caries scores for the first time and scores were adjusted to the old scoring criteria for comparison with data from earlier surveys. It provided a more up to date measure of caries experience but any change in the trend will not be known until the next survey in 2013). The reasons for this apparent lack of improvement need to be addressed.

Once we have satisfied the situations outlined above, we can begin to debate the moral and ethical dilemmas that surround water fluoridation. This debate needs to be balanced on either side of the argument and conducted not restricted to scientists, politicians and lawyers. There is a need to properly engage public consultation and examine the social and sociological issues behind the arguments (Martin 1989).

The Future of Water Fluoridation in the UK – Why is it Still Important?

Whilst it is clear that there are no quick solutions to the issues facing water fluoridation, the overall position is not insurmountable. It is hoped that evidence will continue to support the continuation of existing fluoridation schemes, where they are deemed necessary. It is a paradox that in answering the questions raised by York and the MRC, a new fluoridation scheme would need to be implemented in order to provide research that would meet the criteria required to produce valid data. It would also be hoped that clarification of evidence and continued research will provide an evidence base for the extension of water fluoridation schemes in the UK, again, where it is deemed appropriate. This can only occur with the cooperation of politicians, science and the general public engaging in open, unambiguous and fair consultation. We await the fate of the proposed scheme in Southampton, the outcome of which will have ramifications elsewhere in the country.

Numerous studies and reviews have examined the use of fluorides in caries prevention in children and in adults. The evidence is not conclusive but suggests that the most appropriate way of preventing dental caries is through oral hygiene education, home use of fluoridated dentifrices and the appropriate use of topical fluoride as part of a professionally applied process (Featherstone 2000; Curnow, Pine et al. 2002; Ammari, Bloch-Zupan et al. 2003; Ten Cate 2004; Ammari, Baqain et al. 2007; Griffin, Regnier et al. 2007; Pizzo, Piscopo et al. 2007). However, this is an active form of intervention that requires the compliance of the patient. The fact remains that if a 80:20 model of dental caries (Henry 1997; Dugmore 2006) is true, or the pattern follows a similar trend where the majority of the disease exists in a small percentage of a population it may prove difficult for behaviour change alone to work as a cost effective population based dental public health model. This is further confounded if assumptions based around 80:20 model are not true (Tickle 2002; Tickle, Milsom et al. 2003). This would be particularly true of a population where this cohort belongs to a group of infrequent or non-dental attendees. Recent work has suggested that the risk of a child developing caries is increased with age and once the disease is contracted the risk of developing new lesions increases further compared to caries free children (Milsom, Blinkhorn et al. 2008). Without the ability to accurately assess caries risk we must approach preventative measures on a whole-population basis. This means we should not approach the care of caries-free children and those with caries experience as separate populations. Those who initially attend as caries free cannot be assumed to remain caries free. All patients, irrespective of age, should be encouraged to perform effective oral hygiene, twice daily with appropriate fluoride-containing dentifrice.

There is also a difference between efficacy and effectiveness. Products or interventions can have efficacy demonstrated in clinical trials, but this might not provide answers for the more general or pragmatic evaluation of use in practice. Despite its flaws water fluoridation remains a cost effective population based dental public health intervention. It is non-discriminatory, passive and has the potential to reach more people in need (Pizzo, Piscopo et al. 2007). It may be less efficacious, in principle, than behaviour change, but it could prove more effective in the longer term and provide a more favourable outcome in terms of health economics. In combination with agreed common practises or protocols on the use of other fluoridated products (consumer and professional) water fluoridation may still provide an appropriate adjunctive solution to continuing high caries prevalence in certain populations, whilst minimizing adverse effects such as fluorosis. Recent studies have shown that it is possible to maintain improvement in caries levels with fluoridated dentifrices in areas with the complexity of water supplies that contain varying levels of fluoride, whilst putting in place policies designed to reduce the prevalence of severe fluorosis (Gomez-Santos, Gonzalez-Sierra et al. 2008). This can be obtained through practical advice that engages not only dental professional but also other health care workers, teachers, parents and patients. If such policies can work in areas where they need to address not only variable but high levels of fluoride in the water, then it is not insurmountable to implement similar policies to areas with targeted fluoridation schemes aimed at addressing high caries level populations such as the North West of England.

Further information on the use of fluorides in dentistry and the water fluoridation debate can be found at the British Fluoridation Society website at www.bfsweb.org . Information on the National Pure Water Association campaign for safe, non-fluoridated water can be found at www.npwa.org.uk . The National Fluoride Information Centre (NFIC) is an independent academic unit that provides objective information on the use of fluorides in dentistry. Their website can be found at www.fluorideinformation.com .

References

(1983). Lord Jauncey: Opinion of Lord Jauncey in causa Mrs Catherine McColl (A.P) against Strathclyde Regional Council. The Court of Session, Edinburgh.

Amaechi, B. T. and S. M. Higham (2002). "Quantitative light-induced fluorescence: a potential tool for general dental assessment." J Biomed Opt **7**(1): 7-13.

Ammari, A. B., A. Bloch-Zupan, et al. (2003). "Systematic review of studies comparing the anti-caries efficacy of children's toothpaste containing 600 ppm of fluoride or less with high fluoride toothpastes of 1,000 ppm or above." Caries Res **37**(2): 85-92.

Ammari, J. B., Z. H. Baqain, et al. (2007). "Effects of programs for prevention of early childhood caries. A systematic review." Med Princ Pract **16**(6): 437-42.

Avebury (1984). "Fluoridation and individual freedom." Br Dent J **156**(8): 277.

Berg, J. H. (2006). "Caries detection." J Esthet Restor Dent **18**(1): 3-4.

Boivin, G., P. Chavassieux, et al. (1986). "[Histomorphometric profile of bone fluorosis induced by prolonged ingestion of Vichy Saint-Yorre water. Comparison with bone fluorine levels]." Pathol Biol (Paris) **34**(1): 33-9.

Carmichael CL, Rugg-Gunn AJ, et al. (1989). "The relationship between fluoridation, social class and caries experience in 5 year old children in Newcastle and Northumberland in 1987." British Dental Journal **167**: 57-61.

Castle, P. (1987). The Politics of Fluoridation: The campaign for fluoridation in the West Midlands of England. London, John Libby.

Cheng, K. K., I. Chalmers, et al. (2007). "Adding fluoride to water supplies." BMJ **335**(7622): 699-702.

Chowdhury, N. G., R. H. Brown, et al. (1990). "Fluoride intake of infants in New Zealand." J Dent Res **69**(12): 1828-33.

Coggon, D. and C. Cooper (1999). "Fluoridation of water supplies. Debate on the ethics must be informed by sound science." Bmj **319**(7205): 269-70.

Cohen, H. and D. Locker (2001). "The science and ethics of water fluoridation." J Can Dent Assoc **67**(10): 578-80.

Connett P "50 reasons to oppose fluoridation." Fluoride Action Network, at www.fluoridealert.org.

Cross, D. W. and R. J. Carton (2003). "Fluoridation: a violation of medical ethics and human rights." Int J Occup Environ Health **9**(1): 24-9.

Curnow, M. M., C. M. Pine, et al. (2002). "A randomised controlled trial of the efficacy of supervised toothbrushing in high-caries-risk children." Caries Res **36**(4): 294-300.

de Josselin de Jong, E., F. Sundstrom, et al. (1995). "A new method for in vivo quantification of changes in initial enamel caries with laser fluorescence." Caries Res **29**(1): 2-7.

DOH (1999). "Saving Lives: A Healthier Nation." ISBN 0101438621.

Dugmore, C. R. (2006). "The 80-20 phenomenon (80:20 distribution of caries)--myth or fact." Br Dent J **201**(4): 197-8.

Ekanayake, L. and W. van der Hoek (2002). "Dental caries and developmental defects of enamel in relation to fluoride levels in drinking water in an arid area of Sri Lanka." Caries Res **36**(6): 398-404.

Ekanayake, L. and W. van der Hoek (2003). "Prevalence and distribution of enamel defects and dental caries in a region with different concentrations of fluoride in drinking water in Sri Lanka." Int Dent J **53**(4): 243-8.

Ellwood, R. P., G. M. Davies, et al. (2004). "Relationship between area deprivation and the anticaries benefit of an oral health programme providing free fluoride toothpaste to young children." Community Dent Oral Epidemiol **32**(3): 159-65.

Featherstone, J. D. B. (2000). "The Science and Practice of Caries Prevention." J Am Dent Assoc **131**(7): 887-899.

Fitz-Gibbon, S. (2003). "Truth Decay: Challenging New Labour's propaganda on water fluoridation." Published by Spencer Fitz-Gibbon for the Green Party of England & Wales.

Gomez-Santos, G., M. A. Gonzalez-Sierra, et al. (2008). "Evolution of caries and fluorosis in schoolchildren of the Canary Islands (Spain): 1991, 1998, 2006." Med Oral Patol Oral Cir Bucal **13**(9): E599-608.

Griffin, S. O., B. F. Gooch, et al. (2001). "Quantifying the diffused benefit from water fluoridation in the United States." Community Dent Oral Epidemiol **29**(2): 120-9.

Griffin, S. O., E. Regnier, et al. (2007). "Effectiveness of Fluoride in Preventing Caries in Adults." J Dent Res **86**(5): 410-415.

Grobleri, S. R., A. J. Louw, et al. (2001). "Dental fluorosis and caries experience in relation to three different drinking water fluoride levels in South Africa." Int J Paediatr Dent **11**(5): 372-9.

Groves, B. (2001). Fluoride drinking ourselves to death? Dublin, Newleaf.

Henry, R. J. (1997). "Why do 20% of our children experience 80% of the decay? An update on the status of childhood caries." Tex Dent J **114**(1): 10-4.

Hillier, S., C. Cooper, et al. (2000). "Fluoride in drinking water and risk of hip fracture in the UK: a case-control study." Lancet **355**(9200): 265-9.

Hinds, K. and J. R. Gregory (1995). "National Diet and Nutrition Survey: Children Aged 1½ to 4½ Years." HMSO,London,Report of the Dental Survey.

HM Government (1973). The NHS Reorganisation Act 1973. HMSO: London.

HM Government (1985). Water (Fluoridation) Act 1985. HMSO: London.

HM Government (1991). Water Industry Act 1991. HMSO: London.

HM Government (2000). Water Supply (Water Quality) Regulations 2000. HMSO: London.

HM Government (2003). Water Act 2003. HMSO: London.

Ismail, A. I., W. Sohn, et al. (2007). "The International Caries Detection and Assessment System (ICDAS): an integrated system for measuring dental caries." Community Dent Oral Epidemiol **35**(3): 170-8.

Jackson, P., P. Harvey, et al. (2002). Chemistry and Bioavailability Aspects of Fluorides in Drinking Water. Marlow, Buckinghamshire, WRc.

Jain, P., A. Shankar, et al. (2007). "Dental caries and social deprivation." Lancet **369**(9562): 639.

Juncos, L. I. and J. V. Donadio, Jr. (1972). "Renal failure and fluorosis." Jama **222**(7): 783-5.

K E Haneke and B. L. Carson (2001). Toxicological Summary for Sodium Hexafluorosilicate [16893-85-9] and Fluorosilicic Acid [16961-83-4]. North Carolina, National Institute of Environmental Health Sciences.

Knox, E. G. (1985). Fluoridation of water and cancer: a review of the epidemiological evidence London, HMSO.

Levy, S. M. and N. Guha-Chowdhury (1999). "Total fluoride intake and implications for dietary fluoride supplementation." J Public Health Dent **59**(4): 211-23.

Lowry, R. and D. Evans (1999). "The privatised water industry and public health: back to square one." Br Dent J **186**(12): 597-8.

Lowry, R. J. (2000). "Antifluoridation propaganda material--the tricks of the trade." Br Dent J **189**(10): 528-30.

Maguire, A., F. V. Zohouri, et al. (2005). "Bioavailability of fluoride in drinking water: a human experimental study." J Dent Res **84**(11): 989-93.

Martin, B. (1989). "The sociology of the fluoridation controversy: a reexamination." Sociological Quarterly **30**(1): 59-76.

Milsom, K. M., A. S. Blinkhorn, et al. (2008). "The incidence of dental caries in the primary molar teeth of young children receiving National Health Service funded dental care in practices in the North West of England." Br Dent J.

MRC (2002). Medical Research Council Working Group Report. Water fluoridation and health. London, MRC.

National Research Council (2006). Fluoride in Drinking Water. A Scientific Review of EPA's Standards, The National Acadamies Press.

NHS-CRD (2000). A Systematic Review of Public Water Fluoridation. York, The University of York, NHS Centre for Reviews and Dissemination (Report 18).

Phipps, K. R., E. S. Orwoll, et al. (2000). "Community water fluoridation, bone mineral density, and fractures: prospective study of effects in older women." Bmj **321**(7265): 860-4.

Pizzo, G., M. R. Piscopo, et al. (2007). "Community water fluoridation and caries prevention: a critical review." Clin Oral Investig **11**(3): 189-93.

Pretty, I. A. (2006). "Caries detection and diagnosis: novel technologies." J Dent **34**(10): 727-39.

Provart, S. J. and C. L. Carmichael (1995). "The relationship between caries, fluoridation and material deprivation in five-year-old children in Country Durham." Community Dent Health **12**(4): 200-3.

Ricketts, D. N., K. R. Ekstrand, et al. (2007). "Accuracy and reproducibility of conventional radiographic assessment and subtraction radiography in detecting demineralization in occlusal surfaces." Caries Res **41**(2): 121-8.

Royal College of Physicians (1976): Fluoride Teeth and Health, Pitman Medical. London.

Rugg-Gunn AJ, Carmichael CL, et al. (1977). "Fluoridation in Newcastle and Northumberland: a clinical study of 5-year-old children. ." British Dental Journal **142**: 359-402.

Sheldon, T., S. T. Holgate, et al. (2008). "Is Artificial Fluoride Absorbed to the Same Extent as Natural Fluoride?" Journal of Dental Research **87**(1): 8.

Ten Cate, J. M. (2004). "Fluorides in caries prevention and control: empiricism or science." Caries Res **38**(3): 254-7.

Teotia, S. P. S. and M. Teotia (1994). "Dental Caries: A disorder of high fluoride and low dietary calcium interactions (30 years personal research)." Fluoride **27**: 59-66.

Tickle, M. (2002). "The 80:20 phenomenon: help or hindrance to planning caries prevention programmes?" Community Dent Health **19**(1): 39-42.

Tickle, M., K. M. Milsom, et al. (2003). "The geodemographic distribution of caries experience in neighboring fluoridated and nonfluoridated populations." J Public Health Dent **63**(2): 92-8.

Urbansky, E. T. and M. R. Schock (2000). "Can fluoride affect lead (II) in potable water? Hexafluorosilicate and fluoride equilibria in aqueous solution." Int. J. Environ. Studies **57**: 597-637.

Whelton, H., E. Crowley, et al. (2006). "Dental caries and enamel fluorosis among the fluoridated population in the Republic of Ireland and non fluoridated population in Northern Ireland in 2002." Community Dent Health **23**(1): 37-43.

Yeung, C. A. (2008). "A systematic review of the efficacy and safety of fluoridation." Evid-based Dent **9**(2): 39-43.

Zandona, A. F. and D. T. Zero (2006). "Diagnostic tools for early caries detection." J Am Dent Assoc **137**(12): 1675-1684.

Figure 4.1. Tooth decay in 12 year olds in European Union countries. From Cheng, K K et al. BMJ 2007;335:699-702 (by kind permission of BMJ Publishing Group Ltd).

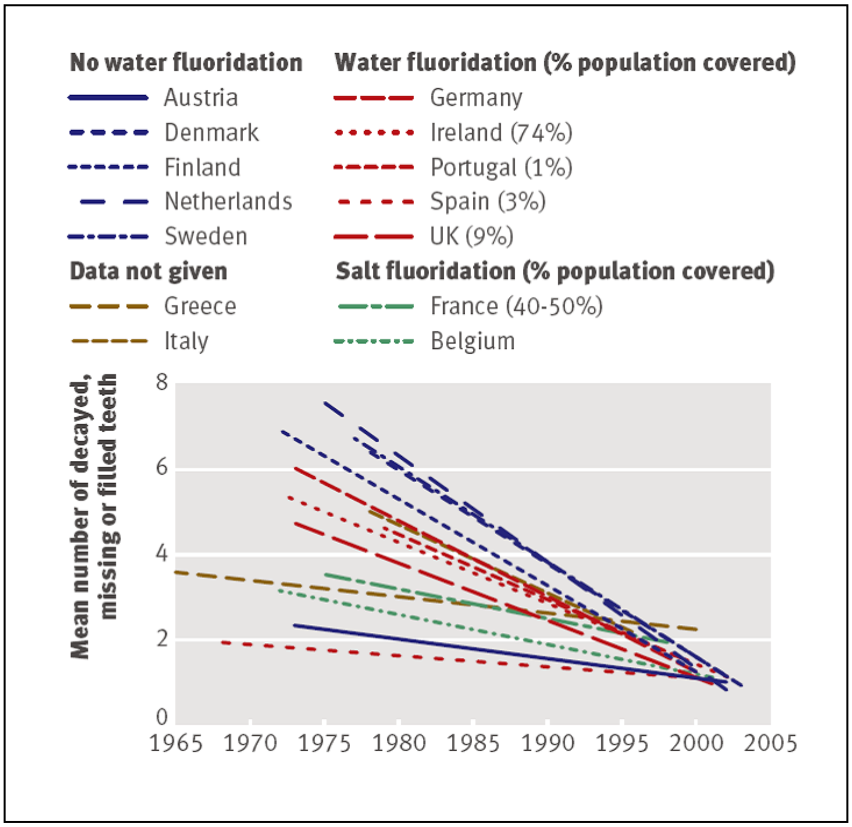
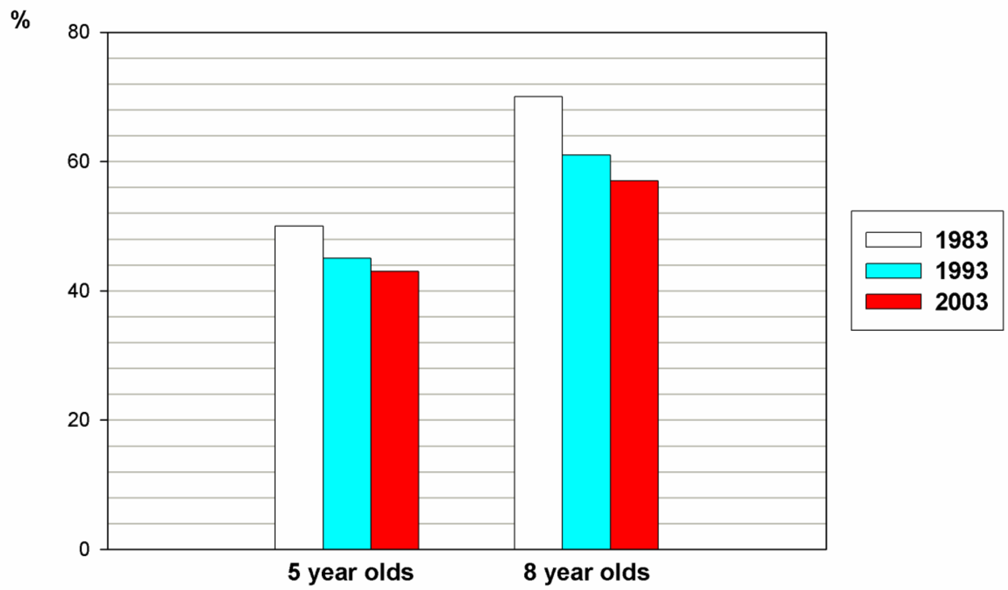


Figure 4.2. Percentage of children with obvious decay experience in primary teeth. Data from Children's Dental Health in the UK 2003



Chapter 5

Dental Fluorosis in Populations with Different Fluoride Exposures, Chiang Mai, Thailand. Paper 1: Assessing Fluorosis Risk and Predictors of Fluorosis

Dental Fluorosis in Populations from Chiang Mai, Thailand with Different Fluoride Exposures.

Paper 1: Assessing Fluorosis Risk and Predictors of Fluorosis

Michael G. McGrady[1], Roger P. Ellwood[1], Patcharawan Srisilapanan[2], Narumanas Korwanich[2], Helen V. Worthington[3], Iain A. Pretty[1]

[1]Colgate Palmolive Dental Health Unit, University of Manchester, England.

[2]Faculty of Dentistry, Chiang Mai University, Thailand.

[3]School of Dentistry, University of Manchester, England.

Running Head: Fluorosis Risk, Chiang Mai, Thailand

Corresponding Author: Michael G McGrady, Dental Health Unit, The University of Manchester, 3A Skelton House, Lloyd Street North, Manchester, M15 6SH.

Abstract

Objectives: To determine the severity of dental fluorosis in selected populations in Chiang Mai, Thailand with different exposures to fluoride and to explore possible risk indicators for dental fluorosis.

Methods: Subjects were male and female lifetime residents aged 8-13 years. For each child the fluoride content of drinking and cooking water samples were assessed. Digital images were taken of the maxillary central incisors for later blind scoring for TF index (10% repeat scores). Interview data explored previous cooking and drinking water use, exposure to fluoride, infant feeding patterns and oral hygiene practices.

Results: Data from 560 subjects were available for analysis (298 M, 262F). A weighted kappa of 0.80 was obtained for repeat photographic scores. The prevalence of fluorosis (TF 3+) for subjects consuming drinking and cooking water with a fluoride concentration of <0.9ppm was 10.2%. For subjects consuming drinking and cooking water >0.9ppm F the prevalence of fluorosis (TF 3+) rose to 37.3%. Drinking and cooking water at age 3, water used for infant formula and water used for preparing infant food all demonstrated an increase in fluorosis severity with increase in water fluoride level ($p<0.001$). The probability estimate for the presentation of aesthetically significant fluorosis was 0.53 for exposure to high fluoride drinking (≥0.9ppm) and cooking water (≥1.6ppm).

Conclusions: High fluoride cooking and drinking water were associated with an increased risk of aesthetically significant dental fluorosis. Fluoride levels in the current drinking and cooking water were strongly correlated with fluorosis severity. Further work is needed to explore fluorosis risk in relation to total fluoride intake from all sources including food preparation.

Background

The benefits of fluoride in the prevention and control of dental caries have been accepted for many years. However, alongside these benefits it is recognized that the ingestion of fluoride during the period of tooth development increases the risk of developing dental fluorosis, a developmental defect seen as hypomineralisation of the enamel (Thylstrup and Fejerskov 1978).

The severity of fluorosis is dependent on a number of factors including the level of fluoride ingested and the time period this ingestion takes place (Hong, Levy et al. 2006; Hong, Levy et al. 2006). Reviews of data generated from water fluoridation and fluoride supplement studies suggest there is a strong linear relationship between the severity of dental fluorosis and the fluoride dose (Fejerskov, Manji et al. 1990; Fejerskov, Larsen et al. 1994).

In populations with low or moderate exposure to fluoride through optimally fluoridated community water supplies and fluoridated dentifrices, fluorosis may present as diffuse white lines or opacities of the enamel surface as a result of an increase in the porosity of the fluorotic enamel. However, in populations exposed to higher levels of fluoride for example, high levels of fluoride in groundwater used for cooking and drinking, fluorosis may manifest as more severe hypomineralization with pitting and loss of the surface enamel. Such a population exposed to high levels of fluoride in groundwater exists in Chiang Mai, Thailand (Takeda and Takizawa 2008).

Chiang Mai Province lies in the Chiang Mai Basin in Northern Thailand. Water is fairly abundant in the form of both surface and ground water. In the cities of Chiang Mai, Doi Saket and Mae Rim the domestic water supply is based largely on surface water. The other cities and villages of the province have water supplies that are derived from groundwater sources (Margane and Tatong 1999). Owing to low awareness of risks of the high fluoride content of the groundwater in the region, endemic dental fluorosis developed in the population (Matsui, Takeda et al. 2006). In response to this efforts were made by the Thai government and the Intercountry Centre for Oral Health (ICOH) to educate the population to the risks of excessive fluoride consumption and to defluoridate the water supply

(Phantumvanit, Songpaisan et al. 1988; Takeda and Takizawa 2008). In the larger communities this could be achieved by defluoridation of the public water supply through the use of reverse osmosis and experimental studies using nano-filtration (Matsui, Takeda et al. 2006). In the smaller villages and communities the use of defluoridators and bone char buckets were introduced. In some areas the continued use of household defluoridators was not successful. This was largely owing to difficulties in replacing filters for ICOH defluoridators that required periodic replacement, a process the ICOH was unable to sustain. As a result the population were advised to use bottled water for drinking. Bottled water is now widely used as the main source for drinking water where defluoridated water cannot be provided (Takeda and Takizawa 2008).

The position in Chiang Mai provides a unique opportunity to explore the effects of fluoride on the dentition in particular the dose response between fluoride and resulting dental fluorosis. The objectives of this study were to determine the severity of dental fluorosis in selected populations with different exposures to fluoride and to explore the risk factors and possible predictors associated with dental fluorosis, in particular water use, infant feeding patterns and oral hygiene practices.

Materials and Methods

The protocol for the study was approved by the Human Experimentation Committee, Faculty of Dentistry, Chiang Mai University, Thailand (clearance number 1/2008) Notification was given to the University of Manchester Committee on Ethics on Research on Human Beings.

The study was an observational cross-sectional survey based on a convenience sample population with varying exposures to fluoride.

Screening and selection of subjects

Subjects were selected with a view to recruiting populations at varying levels of fluoride exposure. The aim was to recruit subjects into approximately six population groups exposed to a range of water fluoride content: <0.01ppm, 0.5ppm, 0.75ppm, 1.00ppm, 1.5ppm, 2+ppm. Subjects were recruited with the aim to obtain equal numbers between the population groups with the pattern of recruitment monitored to reduce imbalance between the population groups. The aim was to recruit approximately 100 subjects in each group. A sample size calculation determined that a continuity corrected χ^2 test with a 0.05 two-sided significance level would have 80% power to detect the difference between a group 1 proportion of 20% and a group 2 proportion of 40% (odds ratio of 2.667) with 91 subjects per group. Schools in the Chiang Mai area were targeted for high expected levels of cooperation and low population mobility. All parents of children in school year groups covering ages 8 to 13 years old were approached to seek consent for their children to participate. A written consent was obtained from the parents with written and or verbal assent obtained from the children. Eligibility criteria for the study required subjects to be lifelong residents of their particular locality, to be in good general health with both maxillary incisors fully erupted and free from fixed orthodontic appliances.

Water samples were collected from all consented subjects in order to determine fluoride content. Samples for drinking and cooking water were obtained. Where a common water supply was used, a single sample analysis was undertaken. Water analysis was carried out by the Science and Technology Service Centre, Chiang Mai University according to an analytical protocol. The fluoride content of the samples was determined using a 4-Star Benchtop pH/ISE meter, Orion Company, Mass, USA. In order to assign the subjects in to groups the data generated from the cooking water were used. This was owing to the fact there was a wider range and variation in the fluoride content of the cooking water compared to the drinking water.

Upon recruitment subjects were assigned a five-digit subject ID number. The first two digits specified the school and the next 3 digits the subject's individual study number based on the sequence of their recruitment.

Photographic Examination

Recruited subjects had conventional digital images taken of the maxillary central incisors. A lip retractor was used to isolate the teeth and the upper anterior teeth were cleaned with a toothbrush and then dried using a cotton wool roll for a period of one minute. The dried teeth were viewed under indirect natural light (not direct sunlight) Standardized digital images were taken with a Nikon D100 camera with a Micro Nikkor 105mm lens and a Nikon SB 21 ringflash using only the upper illumination element. Images were captured at an angle of 15 degrees to perpendicular in order to minimize specula reflection with a 1:1 reproduction ratio (life size). None of the images contained any identifying aspects of the subjects face. A photographic log form was completed to enable the digital files to be linked to the unique subject identifier.

The digital photographic images were exported to a computer and transported to the School of Dentistry, The University Manchester, England. The images were then integrated into a graphical user interface that randomized and blinded the images which were then displayed on a 32 inch flat screen monitor under controlled lighting. A consensus score for Thylstrup and Fejerskov Index (TF) (Thylstrup and Fejerskov 1978) was then given for each image by two examiners (R.P.E and M.G.M). This was recorded directly by the interface into a Windows (Microsoft Corp., Seattle, Wash., USA) excel file and imported into the Statistical Package for Social Sciences (SPSS 16.0) for statistical analysis.

Interview

Each subject and their parent or guardian took part in a structured interview process in their homes with a team of trained interviewers. Information was recorded pertaining to history of residence, school, age and gender. Patterns of water use were also recorded from birth to age three years and current water use for both cooking and drinking e.g. tap, well, ground and bottle (including the brand name). Infant feeding patterns were also investigated such as breast or formula feeding (including the water used for reconstitution) and the types infant foods after weaning, particularly the consumption of rice. The type of water used for the preparation of foods was also noted. Subjects were asked about their oral hygiene practices, when they first started to brush, tooth brushing frequency, brand of dentifrice and whether they swallowed dentifrice. The interview used a combination of close-ended and partially close-ended questions and allowed for validation of some responses. The information from the interview was entered into SPSS and used to verify lifetime residency, age of the subjects and to explore risk indicators for dental fluorosis.

Data Management and analysis

In order to examine the population groups in terms of water fluoride content, frequency distributions of fluoride content were examined for both drinking and cooking water. Appropriate intervals were created according to the frequency distribution of subjects for the fluoride content of the cooking water samples in order to create approximately equal groups. This would attempt to create balanced groups of subjects comparable to the ideals set out at recruitment.

Variables were also created to explore the data with respect to risk factors associated with fluorosis. Interview information on the water source used for drinking and cooking at age three, water used to reconstitute baby formula and water used to prepare infant food were converted into new variables that were comparable to the intervals created for the fluoride content of the current drinking and cooking water from the water sample analysis. Information relating to feeding patterns obtained at interview was converted into a categorical variable: breast feeding alone, formula feeding alone and combination of breast and formula feeding. Variables were also created for the age at which toothbrushing commenced, the frequency of toothbrushing, the fluoride content of toothpaste and gender.

The primary outcome measure for fluorosis was the consensus score from the digital photographs. The basis for this decision was that it was less prone to bias than the clinical score, the examiners were blinded to the probable fluoride exposure and the images were presented in a randomized order. In addition, as the score was a consensus score from two examiners, it would potentially reduce problems associated with examiner personal thresholds related to scoring less severe presentations of fluorosis (TF 1, 2) (Ellwood, O'Mullane et al. 1994). Additional variables were created to group TF scores of 4 and above (TF 4+) within the TF scale and a dichotomous variable of TF scores 0-2 and TF scores 3+ to represent presence or absence of aesthetically significant fluorosis (Hawley, Ellwood et al. 1996). A sample of photographic images were randomly selected and scored again for TF by the examiners in order to assess reproducibility.

A bivariate analysis for each of the risk factors was conducted using ANOVA and χ^2 tests where appropriate. Unadjusted odds ratios were estimated with logistic regression.

A multivariate logistic regression was conducted to identify the explanatory variables considered to be independent indicators of the presentation of aesthetically significant fluorosis (TF score 3+) with a dichotomous TF Index fluorosis score as the dependant variable (TF 3 or less, TF 3+). Using a forward stepwise model, variables were included in the model if they were a significant indicator of the presence or absence of aesthetically significant fluorosis. Variables were excluded if there was multi collinearity or if the variable was found not to be a significant indicator aesthetically significant fluorosis.

Results

Nine hundred and eleven (911) subjects from eleven (11) schools were approached to participate in this survey. Seventy three (73) subjects did not provide consent to participate. Subject accountability is detailed in Figure 5.1. Clinical examinations took place between December 2007 and September 2008. Six hundred and thirty four subjects (634) were included in the study following completion of examinations, photographs and interviews. Subjects were excluded from the examinations if they were deemed to be non-lifetime residents, had unsuitable dentition or if inclusion based on the water fluoride analysis results would have created imbalance in the population groups. Additional subjects were removed from the analysis during data checking and are described in Figure 5.1. Subjects were excluded if information from the interview conflicted with demographic data relating to lifetime residency and age at time of examination. Subjects were also excluded if the upper maxillary teeth could not be ascribed a TF score from the photographs – this would have resulted from the presence of restorations, loss of tooth tissue owing to trauma and presence of extrinsic stain. In total five hundred and sixty (560) subjects were available for analysis. There were 298 males (mean age at exam 10.44, range 8-13) and 262 females (mean age at exam 10.48, range 8-13).

Reproducibility for the photographic image scores was performed on sixty five (65) randomly selected images five (5) months after the original assessments. A weighted Kappa value of 0.80 was obtained (SE 0.05, 95% CI 0.71, 0.89) demonstrating good agreement with the examiners using the full range for TF scores for the images presented. The repeat consensus score for TF was never more than one unit different to the initial assessment.

Descriptive statistics are presented in Table 1 for the distribution of each independent variable for each of the TF score categories. The data illustrates as the mean values of fluoride concentration in current drinking and current cooking water increase the fluorosis severity increases. For subjects with a TF score of 0 the mean fluoride concentration for drinking and cooking water was 0.35ppm (SD 0.37) and 0.65ppm (SD 0.84) respectively. For subjects presenting with TF scores of 4 or higher the mean fluoride content increased to 0.83ppm (SD 0.90) and 2.23ppm (SD 1.52) respectively.

The allocation of subjects to water fluoride intervals based on the frequency distribution of cooking water fluoride content resulted in the creation of five (5) intervals cooking water and four (4) corresponding intervals for drinking water. The details of these intervals and the distribution of subjects are illustrated in Table 5.1.

The variables associated with water interval data demonstrated as the fluoride content of the water increased, greater numbers of subjects presented with fluorosis of increasing severity. This was true of the interval data for current drinking and cooking water derived from the water analysis data and also for the variables created from the interview data. These variables were drinking and cooking water at age three (Drink age 3, Cook age 3), water used for preparing infant food (Water Infant Food) and water used to reconstitute infant formula (Water formula). This pattern was less clear for the variables relating to oral hygiene practices. Insufficient reliable data was available for the reported history of swallowed dentifrice and was excluded from the analysis. This was largely due to a lack of recall. Where this data was available exploratory analysis suggested no pattern associated with the presentation of fluorosis in this population.

There appeared to be no clear pattern in this population between the severity of fluorosis presentation, the age at which tooth brushing commenced, the frequency of toothbrushing and the fluoride content of toothpaste. This was also true of infant feeding practices.

The overall prevalence of fluorosis in the study population was 70.9% (table 5.2.) with a prevalence of aesthetically significant fluorosis (TF 3+) of 16.8%. To evaluate the effect of differing fluoride levels of both drinking and cooking water on fluorosis severity, data was combined into <0.9ppm fluoride and >0.9ppm fluoride categories i.e. grouping together water intervals to produce dichotomous variables. The prevalence of fluorosis among subjects consuming drinking and cooking water <0.9ppm fluoride was 60.6% (10.1% for TF 3+). The prevalence of fluorosis among subjects consuming drinking and cooking water >0.9ppm fluoride was 85.1% (16.8% for TF 3+).

Results of the bivariate analysis of each explanatory variable and TF score are presented in Table 5.3.This was for both the TF score (5 categories) and a dichotomous variable based on the presence or absence of aesthetically significant fluorosis (TF 0-2 versus TF 3+).

Variables for fluoride content of current drinking and cooking water (obtained from water analysis), content of cooking and drinking water at age 3 (obtained from interview data), water used for infant formula, cooking infant food (all obtained from interview data) were all found to have a significant association with the presentation of fluorosis. This was reflected in the unadjusted odds ratios. For current drinking water interval data the odds ratio for the presentation of aesthetically significant fluorosis was 4.02 ($p<0.001$; 95% CI 2.12, 7.63) for subjects consuming drinking water with a fluoride content ≥0.9ppm relative to subjects consuming drinking water <0.2ppm fluoride. For current cooking water interval data the odds ratio for the presentation of aesthetically significant fluorosis was 6.77 ($p<0.001$; 95% CI 2.86, 16.02) for subjects using cooking water with a fluoride content ≥1.6ppm relative to subjects using cooking water <0.2ppm fluoride.

All of the remaining explanatory variables demonstrated no significant association with the presentation of fluorosis. The variables for toothbrushing frequency, age at which toothbrushing commenced and infant feeding pattern were found not to have significant associations with fluorosis score in this population. The one exception was fluoride content of toothpaste which actually demonstrated a decrease in fluorosis with fluoride content of 1000ppm when compared to fluoride content <1000ppm. However, this did not achieve statistical significance ($p = 0.06$).

When all of the variables were entered into a forward stepwise regression analysis the model yielded contained two variables that were the best indicators for the presence of aesthetically significant fluorosis: the fluoride content of the current drinking and current cooking water. However, the attempt to fit a logistic regression model with the continuous variables resulted in the assumptions underlying logistic regression not being upheld. The residuals were strongly related to the fluoride levels for both variables and increased as the water fluoride level increased.

The data was exported to Stata (release 11, StataCorp, TX, USA) for further analysis. A logistic regression model for dichotomised threshold of fluorosis (presence or absence of aesthetically significant fluorosis) with the independent variable for the current drinking water fluoride content coded as water interval data was fitted. The fit improved significantly when the water interval data for current cooking water was added to the model (Likelihood-ratio test, LR χ^2 (4df) = 30.09, <0.001). The clustering of the children within schools was also taken into account by using the robust standard errors. This data is presented in Table 5.4. The odds ratio for the presentation of aesthetically significant fluorosis was 3.34 (robust SE 1.22; 95%CI 1.52, 7.04) for subjects consuming drinking water with a fluoride content equal to or greater than 0.9pmm relative to drinking water consumption with less than 0.2ppm fluoride. The odds ratio for the presentation of aesthetically significant fluorosis was 5.54 (robust SE 3.01; 95%CI 1.91, 16.04) for subjects consuming cooking water with a fluoride content equal to or greater than 1.6ppm relative to cooking water consumption with less than 0.2ppm fluoride.

The presence of any interaction between the fluoride level in the drinking and cooking water was investigated. The overall p-value for this was 0.28 and many of the categories were excluded due to collinearity and small numbers of subjects. Table 5.5 presents the probability estimates and numbers of subjects for each category when these two variables are cross classified. It can be seen the probability of aesthetically significant fluorosis rises to 0.53 if there is exposure to high levels of fluoride in both drinking (≥0.9ppm) and cooking water (≥1.6pmm). There was no evidence of an interaction from the probabilities shown here.

Discussion

The effects of endemic fluorosis in certain regions of Thailand have been known for some time. It is a problem not unique to Thailand, as many areas of Africa and Asia have similar issues with excessive fluoride consumption resulting in efforts to remove excessive fluoride from drinking water employing various techniques such as coagulation-precipitation, adsorption, ion-exchange and more recently nano-filtration (Meenakshi and Maheshwari 2006; Jagtap, Thakre et al. 2009; Mohapatra, Anand et al. 2009). The different techniques are associated with varying levels of effectiveness linked to logistical and financial considerations. The use of reverse osmosis, nano-filtration and bone char defluoridators has been reported in Thailand along with the difficulties associated with the sustainability of such schemes. The use of cheaper alternative methods of defluoridation such as the Nalgonda Technique (popular in parts of India) utilizing alumina, lime and bleach to coagulate and precipitate fluoride from the water supply may not a viable option in this region of Thailand as the sludge produced becomes a waste substance that is difficult to manage. There are also questions regarding the efficacy and sustainability of this technique (Meenakshi and Maheshwari 2006).

In general, the main objective is to provide a community water supply that is safe to drink. In the case of communities supplied by treated surface water the fluoride content of the water supply is lower than treated water from groundwater sources. Nevertheless, the efforts of the Thai government and the ICOH on educating the population with respect to the risks of consuming groundwater with high fluoride content have been successful, although as this was a cross-sectional survey it is not possible to measure the impact of these changes in practice. However, when comparing a subject’s drinking water with their cooking water, 53.2% of subjects consumed drinking water with lower fluoride content. Only 11.4% of subjects consumed drinking water with a higher fluoride content than their cooking water. Where this was the case it was generally as a result of consuming bottled water with low fluoride content while cooking with de-fluoridated or fluoride free community water. When this scenario was cross-tabulated with the TF scores only one subject had a TF score of >3. This suggests the message over the level fluoride in drinking water has been received with some success.

The data suggests in this population the use of cooking water with high levels of fluoride is associated with an increased risk of developing aesthetically significant dental fluorosis. It could be argued the use of data for current drinking and cooking water is inappropriate when assessing the fluorosis status of the subjects. A more appropriate measure would be the use of data obtained from fluoride content of water consumed from birth as part of an assessment of total fluoride intake. An attempt to address this issue was carried out by using data obtained from interview, with the creation of variables of water use at the age of three years comparable to the water intervals derived from the current water sources. Inevitably there would be an element of variance in these variables and also an element of recall bias from interview data.

Nevertheless, the results suggest the best indicators for the presence of aesthetically significant fluorosis were the variables related to current drinking and cooking water. All variables derived from the interview data were excluded from the model during regression analysis (although this was not always necessarily due to a lack of statistical significance but due to the existence of collinearity). Furthermore, the subjects were lifetime residents and the likelihood there had been a change in water supply (particularly cooking water) was low. The spurious result obtained for the fluoride content of toothpaste may be explained by exploring the water fluoride content of the subjects with high TF scores. Without exception these subjects resided in areas with high water fluoride content and were probably advised to use low or non-fluoridated toothpaste. This may also explain why the available data on the swallowing of dentifrice suggested no pattern of association with fluorosis presentation in this population. It is clear from the data in this population there are several factors of great significance that may have a greater impact than the fluoride content of toothpaste and the age at which toothbrushing commences when assessing fluorosis risk.

Several risk factors to fluorosis in this study have not been fully explored or have been found to be non-significant within this population. In the latter case this is more likely to be owing to the lack of robust data or as a result of the implementation of policies to address endemic fluorosis (bottled drinking water, low fluoride toothpaste). This situation arose largely as this study was a cross-sectional survey.

Information relating to infant feeding patterns is essential in assessing fluorosis risk and reliable data for the duration of breast feeding was not available. It was not possible to establish the presence of any protective effect of breast feeding on fluorosis (Levy 1994; Wondwossen, Astrom et al. 2006), or any subsequent fluorosis risk on the cessation of breast feeding or the instigation of alternative/additional feeding patterns. The data obtained from parent interviews was prone to recall bias and, in some cases, information was missing or deemed too unreliable to be used, necessitating the creation of categorical variables such as the variable for feeding pattern to attempt to address this shortfall. Similarly, information on oral hygiene habits would be prone to the same recall bias or missing data and would impact on the validity of the data.

Whilst it is clear it may be possible to use fluoride content of the drinking and cooking water as an indicator in fluorosis risk assessment, the other risk factors for fluorosis cannot be ignored. The range of fluorosis presentation in this population is not remarkable in itself – some subjects have excessive exposure to fluoride resulting in severe fluorosis in a region where there is endemic fluorosis. However, the severity of fluorosis does not appear to be commensurate with this level of fluoride exposure from these sources, even when considering the likely increased intake of water (and hence fluoride) owing to climatic factors (McClure 1943; Galagan and Vermillion 1957; Galagan, Vermillion et al. 1957; Lima and Cury 2003). The levels of fluoride in the drinking water in this population are generally comparable to a society with fluoridated domestic water supplies such as Newcastle, England with fluoride levels adjusted to 1.0ppm fluoride. Earlier work in Newcastle, using the same photographic scoring technique employed in the current study, revealed a prevalence of aesthetically significant fluorosis (TF3+) of 3% (Tabari, Ellwood et al. 2000). A crude assessment of the prevalence of aesthetically significant fluorosis (TF 3+) in the current study population would be 17%. It should be stated this carries the assumptions that the study population are representative of the population as a whole. The increase in fluorosis prevalence in Newcastle was attributed to the increasing use of fluoridated dentifrices in addition to fluoridated water supplies. However, the use of fluoridated dentifrice may not be an important contributing factor in Chiang Mai where it has been demonstrated in this population the majority of children use low or non fluoridated dentifrice. It would appear there are other contributing factors in Chiang Mai. Earlier work on subjects in Thailand failed to reconcile the fluoride intake from water with the urinary excretion of fluoride, there appeared to be an additional source of fluoride intake not being considered (Leatherwood, Burnett et al. 1965). Later work, in a similar population in Thailand, looking at drinking water fluoride content and urinary excretion of fluoride had similar findings, but the differences could be accounted for when considering cooking water and the fluoride content of food (Takeda and Takizawa 2008).

The fluoride content of the food consumed can have an important impact on the quantity of fluoride ingested (Zohouri and Rugg-Gunn 1999; Zohouri, Maguire et al. 2006). Rice is a staple foodstuff in the diet in Thailand and is eaten from an early age. In fact 549 subjects (98%) had reported having routinely eaten some form of rice by the age of three years. As well as being a staple in the diet rice has the capacity to contain high levels of fluoride in its cultivation, preparation and cooking. During the preparation of rice the grains are washed and then soaked for a prolonged period of time in water before cooking. If the water in which the rice is soaked is high in fluoride the resulting soaked rice can become a major source of fluoride intake (Takeda and Takizawa 2008). It has been shown that different methods of preparation and cooking of rice can affect the final fluoride concentration (Anasuya and Paranjape 1996). Nevertheless, it would appear both the water used for soaking the rice and the length of time the rice is soaked have the most profound effect (Takeda and Takizawa 2008). The use of water with a lower fluoride content such as clean rainwater for the washing and soaking process would be more appropriate than using groundwater that has high fluoride content. In addition the water used for cooking should ideally contain low levels of fluoride. Further work is needed to assess the impact of rice preparation on the overall fluoride intake and also the risk of developing fluorosis.

In this survey only the maxillary central incisors were considered in assessing the presence of fluorosis and the determination of fluorosis risk. It should be stipulated this was chosen for logistical reasons alone as these teeth were the only teeth that could be reliably imaged and scored from the photographs for the age range of this population. It should also be stated this paper does not wish to portray the message that fluorosis risk should only be determined for the maxillary central incisors during “periods of vulnerability”. The risk of fluorosis extends across the entire dentition during the period of tooth development and is associated with the cumulative dose of fluoride over this whole time period (Hong, Levy et al. 2006).

In conclusion, the results of this study suggest the use of the fluoride levels in current drinking and cooking water may be a reliable indicator in assessing fluorosis risk or indicating the presence or absence of aesthetically significant fluorosis. However, important risk factors such as infant feeding patterns, water used for reconstituting infant formula and oral hygiene habits should not be ignored when considering the total fluoride ingestion and fluorosis risk. Particular attention should be placed on assessing the total fluoride intake of young children in areas where there is exposure to high levels of fluoride. Further work should be conducted to explore these risk factors preferably in a prospective survey in order to assess the impact on fluorosis risk whilst assessing if there is a seasonal effect on fluoride exposure with respect to water supply. In this body of work it might be preferable to include anthropometric measurements for subjects in order to investigate fluoride dose in addition to total fluoride intake. Additional work should also be considered in assessing the risk associated with water used in the preparation of significant foodstuffs such as rice and education provided in the risks associated with the use of high fluoride water in food preparation.

Acknowledgements

The authors wish to thank the pupils and staff at the schools who participated and staff the Faculty of Dentistry, Chiang Mai University, Thailand for their support and assistance during this project. Dr Pretty is funded by a Clinician Scientist Award from the National Institute for Health Research (UK). This research was supported by Colgate Palmolive Dental Health Unit, Manchester, UK.

References

Anasuya, A. and P. K. Paranjape (1996). "Effect of Parboiling on Fluoride Content of Rice." Fluoride **29**(4): pp193-201.

Ellwood, R., D. O'Mullane, et al. (1994). "A comparison of information recorded using the Thylstrup Fejerskov index, Tooth Surface Index of Fluorosis and Developmental Defects of Enamel index." Int Dent J **44**(6): 628-36.

Fejerskov, O., M. J. Larsen, et al. (1994). "Dental tissue effects of fluoride." Adv Dent Res **8**(1): 15-31.

Fejerskov, O., F. Manji, et al. (1990). "The nature and mechanisms of dental fluorosis in man." J Dent Res **69 Spec No**: 692-700; discussion 721.

Galagan, D. J. and J. R. Vermillion (1957). "Determining optimum fluoride concentrations." Public Health Rep **72**(6): 491-3.

Galagan, D. J., J. R. Vermillion, et al. (1957). "Climate and fluid intake." Public Health Rep **72**(6): 484-90.

Hawley, G. M., R. P. Ellwood, et al. (1996). "Dental caries, fluorosis and the cosmetic implications of different TF scores in 14-year-old adolescents." Community Dent Health **13**(4): 189-92.

Hong, L., S. M. Levy, et al. (2006). "Timing of fluoride intake in relation to development of fluorosis on maxillary central incisors." Community Dent Oral Epidemiol **34**(4): 299-309.

Hong, L., S. M. Levy, et al. (2006). "Fluoride intake levels in relation to fluorosis development in permanent maxillary central incisors and first molars." Caries Res **40**(6): 494-500.

Jagtap, S., D. Thakre, et al. (2009). "New modified chitosan-based adsorbent for defluoridation of water." J Colloid Interface Sci **332**(2): 280-90.

Leatherwood, E. C., G. W. Burnett, et al. (1965). "Dental caries and dental fluorosis in Thailand." Am J Public Health Nations Health **55**(11): 1792-9.

Levy, S. M. (1994). "Review of fluoride exposures and ingestion." Community Dent Oral Epidemiol **22**(3): 173-80.

Lima, Y. B. and J. A. Cury (2003). "Seasonal variation of fluoride intake by children in a subtropical region." Caries Res **37**(5): 335-8.

Margane, A. and T. Tatong (1999). "Aspects of the Hydrogeology of the Chiang Mai-Lamphun Basin, Thailand that are Important for the Groundwater Management." Z. angew. Geol. **45**(4): 188-197.

Matsui, Y., T. Takeda, et al. (2006). Application of Nanofiltration Processes to Fluoride Removal From Groundwaters in the Chiang Mai Basin. In: Proceedings of 32nd WEDC International Conference, Colombo, Sri Lanka.

McClure, F. J. (1943). "Ingestion of fluoride and dental caries: quantitative relations based on food and water requirements of children one to twelve years old " Am J Dis Child **66**(4): 362-369.

Meenakshi and R. C. Maheshwari (2006). "Fluoride in drinking water and its removal." J Hazard Mater **137**(1): 456-63.

Mohapatra, M., S. Anand, et al. (2009). "Review of fluoride removal from drinking water." J Environ Manage **91**(1): 67-77.

Phantumvanit, P., Y. Songpaisan, et al. (1988). A Defluoridator for Individual Households. World Health Forum 9.

Tabari, E. D., R. Ellwood, et al. (2000). "Dental fluorosis in permanent incisor teeth in relation to water fluoridation, social deprivation and toothpaste use in infancy." Br Dent J **189**(4): 216-20.

Takeda, T. and S. Takizawa (2008). Health Risks of Fluoride in the Chiang Mai Basin, Thailand. Groundwater Management in Asian Cities. Technology and Policy for Sustainability. S. Takizawa. Tokyo, Springer**:** pp301-327.

Thylstrup, A. and O. Fejerskov (1978). "Clinical appearance of dental fluorosis in permanent teeth in relation to histologic changes." Community Dent Oral Epidemiol **6**(6): 315-28.

Wondwossen, F., A. N. Astrom, et al. (2006). "Sociodemographic and behavioural correlates of severe dental fluorosis." International Journal of Paediatric Dentistry **16**(2): 95-103.

Zohouri, F. V., A. Maguire, et al. (2006). "Sources of dietary fluoride intake in 6-7-year-old English children receiving optimally, sub-optimally, and non-fluoridated water." J Public Health Dent **66**(4): 227-34.

Zohouri, F. V. and A. J. Rugg-Gunn (1999). "Fluoride concentration in foods from Iran." Int J Food Sci Nutr **50**(4): 265-74.

Table 5.1. Distribution of independent variables for each fluorosis category

	TF 0			TF 1			TF 2			TF 3			TF 4+			
	N	**Mean**	**(SD)**	**N**	**Mean**	**(SD)**	**N**	**Mean**	**(SD)**	**N**	**Mean**	**(SD)**	**N**	**Mean**	**(SD)**	**Row Total**
Water Continuous Data																
Drinking water ppm F	163	0.35	(0.37)	209	0.37	(0.39)	94	0.47	(0.40)	51	0.50	(0.44)	43	0.83	(0.90)	560
Cooking water ppm F (N=560)	163	0.65	(0.84)	209	1.04	(1.02)	94	1.10	(0.87)	51	1.12	(0.93)	43	2.23	(1.52)	560

	TF 0		TF 1		TF 2		TF 3		TF 4+		
	N	**(%)**	**N**	**(%)**	**N**	**(%)**	**N**	**(%)**	**N**	**(%)**	**Row Total**
Water Interval Data (ppmF)											
Drink: <0.20	79	(48)	82	(39)	23	(24)	15	(29)	11	(26)	210
0.2 to 0.59	55	(34)	85	(41)	45	(48)	21	(41)	12	(28)	218
0.6 to 0.89	18	(11)	22	(10)	13	(14)	6	(12)	4	(9)	63
0.9+	11	(7)	20	(10	13	(14)	9	(18)	16	(37)	69
Total	163	(100)	209	(100)	94	(100)	51	(100)	43	(100)	560
Cook: <0.20	52	(32)	39	(19)	5	(5)	6	(12)	1	(2)	103
0.2 to 0.59	44	(27)	36	(17)	21	(22)	7	(14)	3	(7)	111
0.6 to 0.89	37	(23)	44	(21)	25	(27)	12	(23)	5	(12)	123
0.9 to 1.59	18	(11)	49	(23)	21	(22)	12	(23)	11	(26)	111
1.6+	12	(7)	41	(20)	22	(23)	14	(28)	23	(53)	112
Total	163	(100)	209	(100)	94	(100)	51	(100)	43	(100)	560
Drink age 3: <0.20	67	(41)	63	(16)	15	(16)	10	(20)	10	(23)	165
0.2 to 0.59	52	(32)	76	(43)	40	(43)	13	(26)	10	(23)	191
0.6+	44	(27)	67	(42)	39	(41)	28	(54)	23	(54)	201
Total	163	(100)	206	(100)	94	(100)	51	(100)	43	(100)	557

Cook age 3: <0.20	53	(33)	41	(20)	9	(10)	7	(14)	4	(14)	114
0.2 to 0.59	49	(30)	44	(21)	25	(27)	8	(16)	7	(25)	133
0.6 to 0.89	35	(21)	44	(21)	25	(27)	12	(23)	1	(4)	117
0.9 to 1.59	17	(10)	41	(20)	19	(20)	11	(22)	7	(25)	95
1.6+	9	(6)	37	(18)	16	(17)	13	(25)	9	(32)	84
Total	163	(100)	207	(100)	94	(100)	51	(100)	28	(100)	543
Water formula: <0.20	36	(36)	39	(29)	13	(19)	6	(20)	4	(14)	98
0.2 to 0.59	32	(32)	50	(37)	29	(41)	9	(29)	7	(25)	127
0.6 to 0.89	19	(19)	18	(13)	15	(21)	7	(23)	1	(4)	60
0.9 to 1.59	8	(8)	17	(13)	7	(10)	5	(16)	7	(25)	44
1.6+	4	(4)	11	(8)	6	(9)	4	(13)	9	(32)	34
Total	99	(100)	135	(100)	70	(100)	31	(100)	28	(100)	363
Water Infant Food: <0.20	58	(37)	51	(25)	10	(11)	11	(21)	1	(2)	131
0.2 to 0.59	47	(30)	50	(24)	29	(31)	10	(20)	6	(14)	142
0.6 to 0.89	28	(18)	38	(19)	23	(25)	10	(20)	4	(9)	103
0.9 to 1.59	14	(9)	34	(17)	16	(17)	10	(20)	10	(23)	84
1.6+	9	(6)	31	(15)	15	(16)	10	(20)	22	(51)	87
Total	156	(100)	204	(100)	93	(100)	51	(100)	43	(100)	547
	N	**(%)**	**N**	**(%)**	**N**	**(%)**	**N**	**(%)**	**N**	**(%)**	**Row Total**
Oral Hygiene Practices											
Age toothbrush start: 4years+	20	(13)	31	(15)	14	(15)	7	(14)	4	(10)	76
3-4 years	43	(28)	44	(22)	25	(27)	13	(26)	13	(32)	138
2-3 years	48	(31)	67	(33)	34	(37)	14	(28)	15	(38)	178
1-2 years	35	(23)	54	(26)	17	(19)	12	(24)	8	(20)	126
0-1 year	8	(5)	9	(4)	2	(2)	4	(8)	0	(0)	23
Total	154	(100)	205	(100)	92	(100)	50	(100)	40	(100)	541

Toothbrushing freq:1/day	45	(28)	40	(19)	23	(24)	13	(25)	9	(21)	130
2	99	(61)	145	(69)	60	(64)	30	(59)	26	(60)	360
3+	19	(12)	24	(12)	11	(12)	8	(16)	8	(19)	70
Total	163	(100)	209	(100)	94	(100)	51	(100)	43	(100)	560
F content paste: < 1000ppm)	13	(8)	24	(12)	7	(7)	5	(10)	10	(23)	59
1000 ppmF	150	(92)	185	(88)	87	(93)	46	(90)	33	(77)	501
Total	163	(100)	209	(100)	94	(100)	51	(100)	43	(100)	560
Other Variables											
	N	**(%)**	**N**	**(%)**	**N**	**(%)**	**N**	**(%)**	**N**	**(%)**	**Row Total**
Feeding pattern: Breast alone	47	(32)	58	(30)	18	(21)	20	(40)	13	(32)	156
Breast & formula	88	(59)	119	(61)	55	(66)	24	(48)	19	(46)	305
Formula only	14	(9)	17	(9)	11	(13)	6	(12)	9	(22)	57
Total	149	(100)	194	(100)	84	(100)	50	(100)	41	(100)	518
Gender: male	83	(51)	118	(57)	46	(49)	27	(53)	24	(56)	298
female	80	(49)	91	(43)	48	(51)	24	(47)	19	(44)	262
Total	163	(100)	209	(100)	94	(100)	51	(100)	43	(100)	560

Table 5.2. Prevalence data for fluorosis (accounting for combined drinking and cooking water sources)

Combined Water Sources	**Fluorosis Prevalence (n)**				
	TF Score				
	0	**1+**	**2+**	**3+**	**4+**
Drinking water <0.9 ppm F Cooking water <0.9 ppm F	39.4% (132)	60.6% (119)	25.1% (50)	10.1% (25)	2.7% (9)
Drinking water >0.9 ppm F *Cooking water <0.9 ppm F*	*(1)**	*(0)**	*(1)**	*(0)**	*(0)**
Drinking water <0.9 ppm F Cooking water >0.6 ppm F	12.8% (20)	87.2% (70)	42.3% (31)	22.4% (17)	11.5% (18)
Drinking water >0.9 ppm F Cooking water >0.9 ppm F	14.9% (10)	85.1% (20)	55.2% (12)	37.3% (9)	23.9% (16)
Total study population	29.1% (163)	70.9% (209)	33.6% (91)	16.8% (54)	7.7% (43)

*prevalence data not calculated owing to low numbers in cells

Table 5.3. Bi-variate analysis of each risk factor and TF score (as five categories and dichotomised).

	TF Score (5 categories)			**TF 0-2 versus 3+**		
Explanatory Variables : Water Continuous Data obtained by water sample analysis (ppm F)	**ANOVA**			**Binary Logistic Regression**		
	F-ratio	**df**	**p-value**	**Odds Ratio**	**p-value**	**(95% CI)**
Drinking water	11.31	4, 555	<0.001	2.71*	<0.001	(1.75, 4.18)
Cooking water	22.27	4, 555	<0.001	1.67*	<0.001	(1.39, 2.01)
Explanatory Variables: Water Interval Data (ppm F)	**Cross Tabulations**			**Binary Logistic Regression**		
	χ^2	**df**	**p-value**	**Odds Ratio**	**p-value**	**(95% CI)**
Drink (ref <0.20)	45.97	12	<0.001			
0.2 to 0.59				1.26	0.41	(0.73, 2.20)
0.6 to 0.89				1.33	0.47	(0.61, 2.94)
0.9+				4.02	<0.001	(2.12, 7.63)
Cook (ref <0.20)	93.33	16	<0.001			
0.2 to 0.59				1.36	0.55	(0.50, 3.71)
0.6 to 0.89				2.20	0.94	(0.87, 5.33)
0.9 to 1.59				3.58	0.005	(1.47, 8.77)
1.6+				6.77	<0.001	(2.86, 16.02)
Drink age 3 (ref <0.20)	34.62	8	<0.001			
0.2 to 0.59				0.99	0.98	(0.52, 1.88)
0.6+				2.47	0.002	(1.40, 4.34)

Cook age 3 (ref <0.20)	83.582	16	<0.001			
0.2 to 0.59				1.16	0.74	(0.47, 2.87)
0.6 to 0.89				1.87	0.15	(0.80, 4.39)
0.9 to 1.59				3.27	0.005	(1.43, 7.50)
1.6+				6.28	<0.001	(2.82, 13.96)
Water formula (ref <0.20)	40.74	16	= 0.001			
0.2 to 0.59				1.27	0.58	(0.55, 2.93)
0.6 to 0.89				1.35	0.55	(0.50, 3.65)
0.9 to 1.59				3.30	0.12	(1.30, 8.38)
1.6+				5.45	<0.001	(2.10, 14.11)
Water infant food (ref <0.20)	87.13	16	<0.001			
0.2 to 0.59				1.26	0.57	(0.57, 2.77)
0.6 to 0.89				1.56	0.29	(0.69, 3.54)
0.9 to 1.59				3.10	0.004	(1.42, 6.74)
1.6+				5.77	<0.001	(2.76, 12.05)
Explanatory Variables : Oral Hygiene Practices						
	χ^2	**df**	**p-value**	**Odds Ratio**	**p-value**	**(95% CI)**
Age toothbrush starts (ref 4 years+)	11.18	16	0.80			
3-4 years				1.37	0.42	(0.64, 2.96)
2-3 years				1.15	0.72	(0.50, 2.45)
1-2 years				1.12	0.79	(0.54, 2.48)
0-1 year				1.24	0.73	(0.36, 4.36)

Toothbrushing frequency (ref once per day)	6.63	8	0.58			
2				0.90	0.331	(0.53, 1.55)
3+				1.46	0.309	(0.71, 3.00)
Fluoride content of paste (ref < 1000ppm)	9.69	4	0.46			
1000 ppmF				0.55	0.06	(0.29, 1.04)
Other Explanatory Variables						
	χ^2	**df**	**p-value**	**Odds Ratio**	**p-value**	**(95% CI)**
Feeding pattern (ref Breast alone)	12.87	8	0.12			
Breast & formula				0.61	0.61	(0.37, 1.01)
Formula only				1.33	0.43	(0.66, 2.69)
Gender (ref male)	2.04	4	0.729			
female				0.95	0.83	(0.61, 1.48)

* odds ratios reported, but residuals strongly related to the fluoride levels for both variables

Table 5.4.Final Logistic regression model for predicting presence or absence of aesthetically significant fluorosis (TF3+), including the clustering of the children in 11 schools.

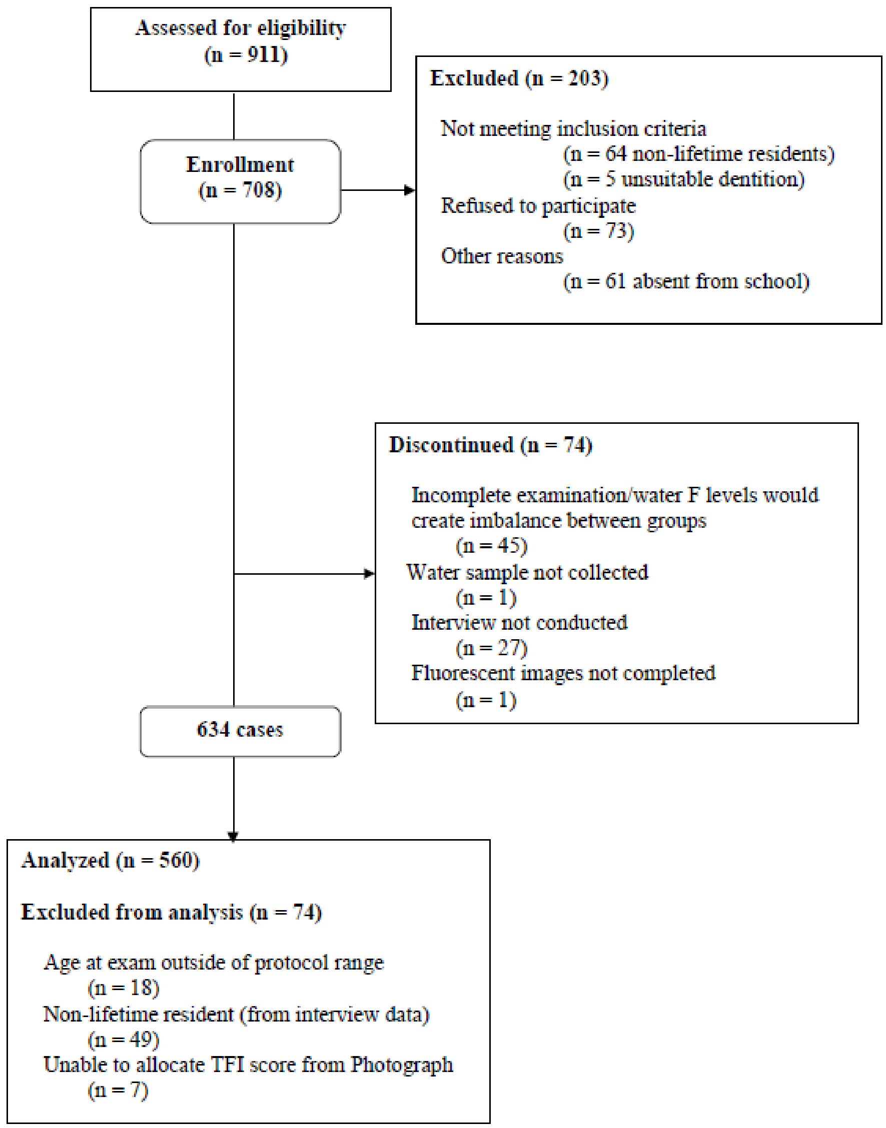
	Odds Ratio (Robust SE)	p-value	(95% CI)
Drink (ppm):		0.019	
0.20 to 0.59	1.35 (0.60)	0.50	(0.66, 2.33)
0.60 to 0.89	1.61 (0.64)	0.23	(0.61, 3.66)
0.9+	3.34 (1.22)	0.001	(1.52, 7.04)
Cook (ppm):		<0.001	
0.20 to 0.59	1.21 (0.74)	0.75	(0.37, 4.03)
0.60 to 0.89	1.85 (0.94)	0.22	(0.69, 5.01)
0.90 to 1.59	1.85 (1.07)	0.29	(0.59, 5.77)
1.6+	5.54 (3.01)	0.002	(1.91, 16.04)

N = 560

Table 5.5. Cross-tabulation of the predicted probabilities of having aesthetically significant fluorosis (TF3+) for the fluoride levels in the drinking and cooking water (number of subjects).

		Cooking Water (ppm)				
		0 to 0.19	**0.20 to 0.59**	**0.60 to 0.89**	**0.90 to 1.59**	**1.60 +**
Drinking Water (ppm)	**0 to 0.19**	0.06 (103)	0.07 (103)	0.10 (32)	0.10 (31)	0.25 (51)
	0.20 to 0.59	0.08 (15)	0.09 (96)	0.13 (46)	0.13 (29)	0.31 (51)
	0.60 to 0.89	0.09(10)	0.11 (3)	0.15 (52)	0.15 (2)	0.35 (4)
	0.9+	-	0.20 (1)	0.28 (2)	0.27 (57)	0.53 (18)

Figure 5.1. Subject accountability illustrating flow of subjects through each stage of the study.



Chapter 6

Dental Fluorosis in Populations with Different Fluoride Exposures, Chiang Mai, Thailand. Paper 2: The Ability of Fluorescence Imaging To Detect Differences in Fluorosis Prevalence and Severity for Different Fluoride Intakes From Water.

Dental Fluorosis In Populations From Chiang Mai, Thailand With Different Fluoride Exposures.

Paper 2: The Ability of Fluorescence Imaging To Detect Differences in Fluorosis Prevalence and Severity for Different Fluoride Intakes From Water.

Michael G. McGrady[1], Roger P. Ellwood[1], Andrew Taylor[1], Patcharawan Srisilapanan[2], Narumanas Korwanich[2], Iain A. Pretty[1]

[1]Colgate Palmolive Dental Health Unit, University of Manchester, England.
[2]Faculty of Dentistry, Chiang Mai University, Thailand.

Running Head: Detection of fluorosis using QLF

Corresponding Author: Michael G McGrady, Dental Health Unit, The University of Manchester, 3A Skelton House, Lloyd Street North, Manchester, M15 6SH.

Abstract

*Objectives***:** To assess the ability of fluorescence imaging to detect a dose response relationship between fluorosis severity and different levels of fluoride in water supplies compared to remote photographic scoring in selected populations participating in an observational, epidemiological survey in Chiang Mai, Thailand.

Methods: Subjects were male and female lifetime residents aged 8-13 years. For each child the fluoride content of cooking water samples (CWS) was assessed to create categorical intervals of water fluoride concentration. Fluorescence images were taken of the maxillary central incisors and analyzed for dental fluorosis using two different software techniques. Output metrics for the fluorescence imaging techniques were compared to TF scores from blinded photographic scores obtained from the survey.

Results: Data from 553 subjects were available. Both software analysis techniques demonstrated significant correlations with the photographic scores. The metrics for area affected by fluorosis and the overall fluorescence loss had the strongest association with the photographic TF score (Spearman's rho 0.664 and 0.652 respectively). Both software techniques performed well for comparison of repeat fluorescence images with ICC values of 0.95 and 0.85 respectively and were able to discriminate between the water intervals to a comparable level to remote scoring of photographic images.

Conclusions: This study supports the potential use of fluorescence imaging for the objective quantification of dental fluorosis. Fluorescence imaging was able to discriminate between populations with different fluoride exposures on a comparable level to remote photographic scoring with acceptable levels of repeatability.

Background

The measurement of the prevalence and severity of enamel fluorosis in populations for both epidemiological purposes and the evaluation of fluorosis risk associated with therapeutic interventions has traditionally been carried out using clinical indices such as Dean’s Index (Dean 1942), the Fluorosis Risk Index (FRI) (Pendrys 1990), Thylstrup and Fejerskov Index (TF) (Thylstrup and Fejerskov 1978) and the Tooth Surface Index of Fluorosis (TSIF) (Horowitz, Driscoll et al. 1984). The use of each of these indices requires an examiner to visually assess a tooth surface and by using predetermined criteria allocate a score as an interpretation of the aetiology and severity of the clinical presentation. Despite the wealth of historical data from studies using clinical indices criticism of their use exists (Angmar-Mansson, de Josselin de Jong et al. 1994; Rozier 1994; NHS-CRD 2000; MRC 2002). This is particularly true when considering the fact the indices are subjective and can be prone to bias (knowledge of the fluoridation status of a population under examination), inter-examiner differences and personal thresholding associated with the presentation of fluorosis at low levels of severity (Ellwood, O'Mullane et al. 1994; Tavener, Davies et al. 2007). This results in difficulties during the comparison and interpretation of multiple studies that have used subjective indices. It is possible to avoid the “blinding” issue of clinical examinations by moving the population to a central or distant location for examination, but this can be associated with logistical issues (Milsom and Mitropoulos 1990; Stephen, Macpherson et al. 2002). Remote scoring of clinical photographs can address issues of blinding so examiners have no knowledge of the fluoride exposure of the subjects under assessment (Tavener, Davies et al. 2007). This method of assessment can provide data considered to be more robust when compared to data obtained from direct clinical assessment. There are additional benefits with the use of clinical photographs. It is possible to capture digital images that are not only of high quality but can be archived and used for longitudinal and repeat assessments, clinical and research governance and audit processes.

Although the scoring of clinical photographs may address potential bias from blinding and carries advantages over direct clinical assessment, it still relies upon the application of a subjective index by an examiner that is still prone to such issues as personal thresholding and variability between and within examiners. In addition, the magnification of images could result in a tendency to over score fluorosis for milder severities.

Alternative means of assessing fluorosis by methods that are both quantitative and objective would be considered desirable. The possibilities of optical techniques with and without the diagnostic judgment of a clinician have been explored (Angmar-Mansson, de Josselin de Jong et al. 1994).The ability to quantify demineralization in early enamel lesions has been demonstrated and validated using changes in fluorescence (de Josselin de Jong, Buchalla et al. 2003). The technique quantifies the loss of fluorescence due to demineralization of enamel in a lesion relative to the surrounding sound enamel providing information on the percentage fluorescence loss (ΔF) relative to sound surrounding enamel and the Area (mm^2) in which this loss of fluorescence occurs. The determination of overall mineral loss (ΔQ) is a metric derived from the product of ΔF and Area.

As both dental caries and enamel fluorosis are phenomena relating to hypomineralized enamel, an opportunity to objectively quantify fluorosis arises. Confounding factors exist that complicate this approach. Fluorescence imaging relies upon the image analysis software to reconstruct the lesion relative to sound surrounding enamel i.e. mineral loss occurring as discrete lesions. Fluorosis differs in its appearance as it presents as diffuse lesions that may extend across the whole tooth surface (Ellwood and O'Mullane 1995). This prevents the use of image processing techniques used in the assessment of carious lesions being employed to quantify fluorosis as it becomes more difficult to reconstruct defuse lesions relative to sound enamel.

Novel software techniques and imaging systems have been developed in order to utilize fluorescence imaging in order to assess and objectively quantify enamel fluorosis and these have been tested in vivo (Pretty, Tavener et al. 2006). It was found it was possible to quantify fluorosis using fluorescence imaging and overcome the issues associated with the assessment of diffuse lesions with no clear sound area to act as reference. Using this technique an image blurring methodology was applied to the green channel of the bitmap image obtained from fluorescence imaging. The blur technique involved the averaging of pixels within a matrix of pre-determined size replacing each point in the image with the average value of the surrounding pixels. The greater the size of the matrix, the larger the blur effect as more pixels are averaged. On completion of the blur process the "unsharp-mask" was subtracted from the original image leaving those areas considered to be fluorosis. The blur image acts as the control or sound area required for reconstruction of the lesion. The authors decided the optimum parameters were found by employing a blur effect at 30 pixels with a pixel selection of 2 standard deviations from the base level. This had the highest correlation with the clinical scores using TF index (Kendall's Tau 0.869) when the metric of ΔQ_{blur} was chosen as the summary variable. Artifacts created by the blur technique tended to underestimate both the fluorescence loss (ΔF_{blur}) and $Area_{blur}$, particularly at higher levels of fluorosis severity where there is less "sound" enamel to act as a reference.

The purpose of this study was to further develop the use of fluorescence imaging for the analysis of fluorosis. The study aimed to examine a population with a wide range of fluoride ingestion from drinking and cooking waters and hence potential fluorosis experience. This approach provides a wide range of fluorosis presentation to assess the system's ability to detect a dose response to changes in fluoride exposure from water sources when compared to a randomized blinded score of TF index obtained from conventional digital photographs. The study also aimed to evaluate the use of an alternative system of analysis for the fluorescence images in order to address the issues relating to the artifacts created with the existing blur technique and the resulting effects on the metrics of ΔF_{blur} and $Area_{blur}$.

Materials and Methods

Screening and selection of subjects

Subjects selected for this study had participated in an epidemiological survey looking at fluorosis in Chiang Mai, Thailand. The protocol for the study was approved by Human Experimentation Committee, Faculty of Dentistry, Chiang Mai University, Thailand (clearance number 1/2008) (with notification to the University of Manchester Committee on Ethics on Research on Human Beings). The subjects were healthy males and females aged 8-13 years old. Written consent was obtained from the subjects and their parents.

Water samples were collected from all consented subjects in order to determine fluoride content for both the drinking water supply and the cooking water supply. Where a common water supply was used, a single sample analysis was undertaken. Water sample analysis was carried out according to an analytical protocol by the Science and Technology Service Centre, Chiang Mai University. The fluoride content of the samples was determined using a 4-Star Benchtop pH/ISE meter, Orion Company, Mass, USA. The subjects were assigned to groups of different water fluoride content intervals based upon the data generated from the cooking water samples. This was owing to the fact there was a wider range and variation in the fluoride content of the cooking water compared to the drinking water. The aim was to recruit equal numbers of subjects into groups representing a range of fluoride concentration in the water supply.

Consented subjects were recruited on the basis of the fluoride content of drinking and cooking water samples and were assigned a five-digit subject ID number. The first two digits specified the school and the next 3 digits the subject's individual study number based on the sequence of their recruitment. During the observational survey all subjects had standardized conventional digital photographs taken of the maxillary central incisors after the teeth had been cleaned and dried (Cochran, Ketley et al. 2004). An example image is illustrated in Figure 6.1a. A consensus score by two examiners (RPE, MGM) based at a remote location was performed on the images that were presented in a randomized and blind manner.

Fluorescence Image Capture.

The imaging equipment comprised a high-resolution 3 CCD camera (Jai M91P, Jai Corp., Copenhagen, Denmark) fitted with a 16-mm F1.4 lens (Pentax, Slough, UK) and a long-pass yellow filter (495 nm, Schott, Stafford, UK). The light source was a custom made LED array with variable illumination emitting light with peak source at 405-nm. A custom-built stabilizing unit, comprising an adjustable head and chin support and a camera focus platform to which the camera and illuminator were connected enabled the camera to be moved and focussed while the subject remained static Figure 6.1b).

A number of subjects were randomly invited to have repeat fluorescence images taken in order to assess the repeatability of the image capture and image analysis procedures.

Software

The software used for the existing technique utilized MATLAB version 7.6.0 (R2008a, Mathworks, N.Y., USA) image processing software to analyze the bitmap images obtained from the fluorescence image capture. A series of process applications included the image blur, the subtraction mask and the analysis of the resultant image (Figure 6.1c). The technique is described in detail in the literature (Pretty, Tavener et al. 2006).

An alternative analysis software was utilized that was originally designed to quantify stain on teeth (Taylor, Ellwood et al. 2009). The hypothesis was that as the software was designed to detect diffuse areas on the tooth surface using an algorithm based on a convex hull and therefore may be able to detect and quantify the diffuse areas of hypomineralization associated with fluorosis. The convex hull analysis software quantified the level of hypomineralization of the tooth surface image captured using the fluorescence imaging system. A number of stages were required in order to process the image (Figure 6.1d). The software was able to utilize the same masks of the object teeth created by a region of interest tool and employed by the existing technique. Prior to processing, the mask of the image was utilized in order to exclude any pixels outside of the tooth. The image reconstruction process was carried out in several stages. Firstly, the analysis software detected dark areas by reconstructing a “clean” image of the tooth surface and then subtracted the captured image. The reconstruction converted the image into a set of coordinates in the dimensions *x*, *y* and *brightness*. The convex hull of these points in these three dimensions was then calculated using the Quickhull algorithm written at the Geometry Center, University of Minnesota (Barber, David et al. 1996). The convex hull was then converted back to an image using a simple software rendering algorithm. The result was an image of the tooth where dark areas were filled with an interpolation between surrounding areas. The map of fluorescence loss could then be thresholded to remove background noise, with all pixels below the threshold set to zero and all those above the threshold included in the map. In this study in order to include milder forms of fluorosis the threshold was set at a level of 5 (out of 255) pixels.

During analysis only the green channel was used and noise reduction was carried out by morphological opening before the reconstruction occurred. The development of the convex hull software and greater detail of the analysis processes are described in the literature (Taylor, Ellwood et al. 2009). Metrics were produced relating to the fraction of tooth area considered fluorosis ($Area_{ch}$), the average fluorescence loss of areas considered fluorosis (ΔF_{ch}) and the average fluorescence loss over the entire tooth surface (ΔQ_{ch}).

Repeat fluorescence images captured for randomly selected subjects underwent a complete analysis procedure for both software analysis techniques. The same mask created from the repeat fluorescence images was utilized by both software analysis techniques to provide consistency with the main study data. The reproducibility data for the photographic assessments delivered a Kappa statistic of 0.80 (previously reported in **Chapter 5**).

Statistical Analysis

The data for the photographic TF index scores from the epidemiological survey were entered into the Statistical Package for Social Sciences (SPSS 16.0) along with the metrics from the analysis of the fluorescence images using the existing technique and the convex hull software. For each subject, the higher of the two scores on the maxillary central incisors was used in the statistical analysis. Correlation coefficients between the photographic scores and the output from the software analyses were determined using for comparison with the QLF metrics ($Area_{blur}$ ΔF_{blur} ΔQ_{blur} and $Area_{ch}$ ΔF_{ch} ΔQ_{ch}).

The data on cooking water fluoride content was converted into a categorical variable based upon concentration ranges separating the data into intervals. This is illustrated in Table 6.1. In order to assess the ability of either fluorescence image analysis technique to detect differences in fluoride exposure i.e. between each of the water intervals, a one-way ANOVA was conducted with a post-hoc correction for multiple comparisons. A non-parametric analysis using Mann-Whitney U Test would be employed if the assumptions for ANOVA were not upheld.

Results

Data for 560 subjects were available for analysis. After data cleaning 553 subjects were included in the analysis. Seven subjects were removed from the analysis owing to problems associated with processing the masks of the dentition. This occurred when there was either a missing mask (missing, fractured or restored incisor) or there was a large diastema between the central incisors. A decision was taken to exclude these subjects from the analysis rather than processing the image masks manually to ensure all images were analyzed using the same technique. Descriptive statistics for each of the assessment methods are described in Table 6.1. The subject distribution in each water interval was approximately equal. All of the outcomes demonstrated an increase in mean scores with increasing water fluoride content. The exception to this was the ΔF metric for the existing technique corresponding to the two water intervals with the lowest water fluoride content.

The ability of the photographic scoring to detect differences in fluorosis severity at different exposures to fluoride is illustrated in Figure 6.2. Boxplots for the metric for ΔQ for both software analysis techniques demonstrated an increase in ΔQ as the TF index score increased (Figures 6.2 and 6.3). A one-way ANOVA between the photographic score and the fluorescence image analysis was performed with a Bonferroni correction for multiple comparisons. Analysis revealed the assumptions for ANOVA were not fully upheld. A test of the homogeneity of variances delivered a positive Levine's statistic. In light of this a non-parametric analysis was performed using Mann-Whitney U Test with a simple Bonferroni correction for multiple comparisons. A summary of the ability of each technique to separate the water intervals is shown in Table 6.2. Overall, the convex hull software appeared to be almost as sensitive as the photographic score at discriminating between the water intervals when correcting for multiple pair-wise comparisons. The existing technique appeared to perform less well at lower water fluoride levels. All of the techniques performed less well for comparisons between water intervals 1 and 2 and water intervals 2 and 3.

The results of the correlations between the photographic scores and the fluorescence imaging output (Area, Δ F and ΔQ) are shown in Table 6.3. Both image analysis techniques demonstrated significant correlations with the photographic scores. Overall, the convex hull analysis software demonstrated a better association with the photographic scores than the existing technique for all outcome metrics. The metrics with the strongest correlations (Spearman's rho) with the photographic score were $Area_{ch}$ (0.66) and ΔQ_{ch} (0.65). The correlation for ΔQ_{blur} was still significant but was not as strongly correlated with the photographic scores (0.56).

An intraclass Correlation Coefficient (ICC) was obtained for each the fluorescence image analysis metrics. This data is illustrated in Table 6.4. The ICC for the convex hull software were all considered to be "very good", the metric for ΔQ_{ch} delivering a value of 0.95. The values for the existing technique were slightly lower but still considered very good with a value of 0.85 obtained for the metric ΔQ_{blur}.

Discussion

The findings of this study support the potential use of fluorescence imaging to objectively quantify dental fluorosis. This is consistent with earlier work (Pretty, Tavener et al. 2006). However, the correlation coefficients in the current study are lower than those obtained by Pretty et al (Pretty, Tavener et al. 2006). This is probably due to the fact the population in the original study was a selected population based upon the presence of fluorosis in an area of optimal water fluoridation and presented with only milder forms of dental fluorosis. The population in the current study is larger and presents with a greater range of fluorosis severity and the increased presence of confounding factors. Nevertheless, the repeatability of both techniques is very good with the ICC for the existing technique being commensurate with the findings of Pretty et al and the convex hull software delivering even greater performance. This was achieved without employing techniques such as video repositioning and as such supports the claim that fluorescence image analysis can be robust in terms of the repeatability of measures (Pretty, Tavener et al. 2006).

There are certain considerations to be made regarding the population selected in this study. The population was selected according to the level of fluoride in their cooking water. Despite the fact the TF score obtained from the photographs was able to separate the different water fluoride content intervals (Figure 6.2) (suggestive of a dose response) it is clear this is not a true reflection of the fluoride exposure of the subjects. The risk to developing enamel fluorosis must include all forms of fluoride ingestion at the time of tooth development not only from cooking water but also drinking water, beverages, food and oral hygiene products (Hong, Levy et al. 2006; Hong, Levy et al. 2006; Zohouri, Maguire et al. 2006). It would be problematic to use total fluoride exposure to assess dose response in this population on this study and it should be accepted the use of cooking water fluoride content is not indicative when evaluating a dose response. However, this population was selected as lifetime residents and the likelihood the cooking water source had changed since birth was low. It had also been demonstrated that the current cooking water fluoride content was a strong measure when determining fluorosis risk (Takeda and Takizawa 2008).

Looking at the ranges of water fluoride content of the intervals (Table 6.1) intervals 0 and 1 could be seen to represent non-fluoridated populations with perhaps some background fluoride in water. Intervals 2 and 3 are commensurate with sub-optimal and optimally fluoridated populations with interval 4 representing fluoride levels above optimal levels. It would be desirable that any system would be able to discriminate between each of the intervals. However, it could be argued at the levels set in this study the difference between intervals 0, 1, 2 and 3 is minimal and the inability to discriminate between intervals 0 and1 is not critical. However, a robust system should be able to discriminate between interval 4 and the remaining intervals.

Whilst the outcome of this study supports the development of fluorescence imaging as a technique for objectively quantifying enamel fluorosis, there remain several unresolved issues from the work of Pretty et al. Firstly there is still no acceptable gold standard to use. The use of the photographic score as the comparator remains inadequate as it depends upon a subjective assessment of fluorosis. The conventional digital photograph requires the camera to be position at an angle to the teeth (approximately 15° to the perpendicular plane) to reduce specula reflection, whereas the fluorescence imaging uses flat field illumination and polarizing filters enabling the images to be captured perpendicular to the teeth. This results in potential differences in the information that can be displayed between the images owing to foreshortening of the photographic image. Furthermore it is still not possible to relate the TF score from the photographs to the metrics obtained from either of the fluorescence analysis techniques. This is not a situation unique to the assessment of fluorosis, similar issues existed when fluorescence imaging was used for the assessment of carious lesions (ten Bosch 2000). This would be true of any novel technique utilizing emerging technologies. Nevertheless, both fluorescence imaging techniques demonstrate an increase in ΔQ with increasing TF index score (figures 6.5 and 6.6).

The statistical analysis of the data is also compromised by the differences in the metric outputs. The correlation coefficients presented in this paper should not be regarded as a measurement of agreement as they are merely an indication of association between the different techniques. This is not only true of the comparison between the photographic scores and the fluorescence imaging but also between the two fluorescence imaging techniques. Despite similarities between the fluorescence imaging techniques, the methods by which the metrics are derived differ. The outputs whilst delivering the same outcome measures are presented using different scales.

In order to reduce variance between the two fluorescence imaging techniques it was necessary to utilize the same masks of the teeth. The software in the original study required the operator to draw around the object teeth with a region interest tool. It is clear that repetition of this process could result in variance. Furthermore the original software required a reference area to be selected using the region of interest tool. This was overcome by using software written in Visual C# (2005 Express Edition, Microsoft, Inc., CA, USA) to process masks for all the object teeth from the fluorescence images. The software for the existing technique was augmented by the addition of an algorithm written in MATLAB that automatically selected a reference area from the triangulation of a point located on the gingival tissues with the masks of the maxillary central incisors (with an assumption of the location of the teeth). This algorithm worked well but was unable to process the analysis if there was either a missing mask (missing, fractured or restored incisor) or there was a large diastema between the central incisors. If this occurred the subjects and data were excluded from the analysis. This resulted in the exclusion of seven subjects.

The inability of the fluorescence imaging techniques to differentiate fluorosis from caries and other non-fluorotic developmental defects of enamel still exists. The subjects illustrated in Figure 6.5 demonstrate issues that can arise from this phenomenon. The images of subject 545 illustrate how the presence of caries and stain can impact upon the fluorescence image and subsequent analysis. The presence of plaque, stain, caries and other developmental defects of enamel such as demarcated enamel opacities are confounding factors in fluorosis assessment using fluorescence imaging (McGrady, Browne et al. 2008). It has been shown that demarcated opacities with similar clinical presentations can exhibit markedly different changes in fluorescence with some opacities demonstrating a loss of fluorescence whilst others demonstrating an increase in fluorescence signal.

Subject 837 (Figure 6.5) had suffered from a large developmental defect localized to the right maxillary central incisor with an aetiology non-fluorotic in nature. Both imaging techniques were unable to differentiate this from fluorosis and hence large values for Area, ΔF and ΔQ whereas the score allocated from the photograph for this subject was TF 0.

The images of subject 230 (Figure 6.5) illustrate fluorosis that has developed post eruptive stain. Whilst the existing technique was able to process this image the convex hull software was unable to differentiate the change in fluorescence relative to the surrounding unstained fluorosis and would have deemed the areas of discolouration as “heavy stain” and allocated a higher score for ΔF and ΔQ accordingly.

It is clear further work is needed if fluorescence imaging techniques are to be used for objectively quantifying fluorosis. It has been shown it can discriminate between populations with differing fluoride exposures. It is arguable which analysis technique is the more appropriate technique. The convex hull software would appear to be more sensitive than the existing technique at low fluoride exposures. This is likely to have been caused by the low threshold level set on this study. This was necessary to avoid excluding milder forms of fluorosis but would have included greater levels of noise in the analysis, affecting specificity. In fact the data suggests the ability of the convex hull software to discriminate between levels of fluorosis severity is comparable to the use of photographic scores. The existing technique appears to work well at higher severities of fluorosis. This is in contrast to the findings of Pretty et al who hypothesized that artifacts created by the existing technique may underestimate fluorosis. This may have been based on the findings from a population with lower exposures to fluoride and lower severities of fluorosis presentation. Overall both fluorescence image analysis techniques appear to be less sensitive than clinical judgment using an index when considering the whole range of presentations of fluorosis. Although in the case of the convex hull software this is marginal.

Although image capture is simple and reproducible it remains an additional step in study procedures. In addition, despite the fact the analysis is automated, there remains a considerable operator task in drawing the masks for image processing. At present it would appear the use of at least a photographic score using TF index and the application of diagnostic criteria cannot be dispensed with. The question arises as to what additional value can the use of fluorescence imaging provide over and above a clinical index? The answer may lie in the fact the longitudinal assessment of fluorosis is desirable and the variation in examiner scoring using a clinical index could be problematic when assessing prevalence and severity by clinical examination (Ellwood, O'Mullane et al. 1994; Ellwood and O'Mullane 1994; Tavener, Davies et al. 2007). This can be avoided with the use of photographic scores, but the problem of subjectivity would remain.

Further software development is required particularly with respect to the production of the masks of the object teeth as this is the time dependant process that questions the viability of the application in a large epidemiological survey. Possible avenues to explore would be the production of automatic masks using edge detection software or more simply the use of preset polygons in Visual C# that can be adjusted to the shape of an object tooth rather than masks drawn freehand.

A possible interim solution could be to use a dual-camera system for image capture using two high resolution CCD cameras with an illumination and lens array that would permit one camera to capture a fluorescence image and a second to capture a polarized white light image (negating the need for camera repositioning to reduce specula reflection). Both sets of images would be of the same position relative to the teeth, same magnification and would both be amenable to longitudinal assessment through the use of video-repositioning software. Any white light image score using an index can remain blind and randomized and quantifiable metrics of fluorosis obtained from the corresponding fluorescence image.

In conclusion, this study has shown that fluorescence imaging techniques can discriminate between populations with different fluoride exposures and a wide range of fluorosis severity. Both fluorescence image analysis techniques demonstrated very good levels of repeatability. The data support the early work in this field but further work is needed to develop the capturing system and software if it is to become a viable means of objectively quantifying fluorosis in large scale epidemiological surveys. At present there appears to be no means of avoiding the use of either the application of diagnostic criteria or the use of a clinical index in conjunction with fluorescence imaging for the objective quantification of fluorosis.

Acknowledgements

The authors wish to thank the pupils and staff at the schools who participated and staff the Faculty of Dentistry, Chiang Mai University, Thailand for their support and assistance during this project. Dr Pretty is funded by a Clinician Scientist Award from the National Institute for Health Research (UK). This research was supported by Colgate Palmolive Dental Health Unit, Manchester, UK.

References

Angmar-Mansson, B., E. de Josselin de Jong, et al. (1994). "Strategies for improving the assessment of dental fluorosis: focus on optical techniques." Adv Dent Res **8**(1): 75-9.

Barber, C. B., P. D. David, et al. (1996). "The quickhull algorithm for convex hulls." ACM Trans. Math. Softw. **22**(4): 469-483.

Cochran, J. A., C. E. Ketley, et al. (2004). "A standardized photographic method for evaluating enamel opacities including fluorosis." Community Dent Oral Epidemiol **32 Suppl 1**: 19-27.

de Josselin de Jong, E., W. Buchalla, et al. (2003). QLF: New Developments. Early Caries Detection III, Indiana, Indianapolis, Indiana University Press.

Dean, H. T. (1942). The investigation of physiological effects by the epidemiological method. Fluorine and Dental Health. F. R. Mouton. Washington (DC), American Association for the Advancement of Science**:** 23-31.

Ellwood, R., D. O'Mullane, et al. (1994). "A comparison of information recorded using the Thylstrup Fejerskov index, Tooth Surface Index of Fluorosis and Developmental Defects of Enamel index." Int Dent J **44**(6): 628-36.

Ellwood, R. P. and D. O'Mullane (1995). "Enamel opacities and dental esthetics." J Public Health Dent **55**(3): 171-6.

Ellwood, R. P. and D. M. O'Mullane (1994). "The demographic and social variation in the prevalence of dental enamel opacities in north Wales." Community Dent Health **11**(4): 192-6.

Hong, L., S. M. Levy, et al. (2006). "Timing of fluoride intake in relation to development of fluorosis on maxillary central incisors." Community Dent Oral Epidemiol **34**(4): 299-309.

Hong, L., S. M. Levy, et al. (2006). "Fluoride intake levels in relation to fluorosis development in permanent maxillary central incisors and first molars." Caries Res **40**(6): 494-500.

Horowitz, H. S., W. S. Driscoll, et al. (1984). "A new method for assessing the prevalence of dental fluorosis--the Tooth Surface Index of Fluorosis." J Am Dent Assoc **109**(1): 37-41.

McGrady, M. G., D. Browne, et al. (2008). "Differentiation of demarcated enamel opacities from fluorosis using quantitative light-induced fluoroescence." Caries Research **42**: 213.

Milsom, K. and C. M. Mitropoulos (1990). "Enamel defects in 8-year-old children in fluoridated and non-fluoridated parts of Cheshire." Caries Res **24**(4): 286-9.

MRC (2002). Medical Research Council Working Group Report. Water fluoridation and health. London, MRC.

NHS-CRD (2000). A Systematic Review of Public Water Fluoridation. York, The University of York, NHS Centre for Reviews and Dissemination (Report 18).

Pendrys, D. G. (1990). "The fluorosis risk index: a method for investigating risk factors." J Public Health Dent **50**(5): 291-8.

Pretty, I. A., J. A. Tavener, et al. (2006). "Quantification of dental fluorosis using fluorescence imaging." Caries Res **40**(5): 426-34.

Rozier, R. G. (1994). "Epidemiologic indices for measuring the clinical manifestations of dental fluorosis: overview and critique." Adv Dent Res **8**(1): 39-55.

Stephen, K. W., L. M. Macpherson, et al. (2002). "A blind caries and fluorosis prevalence study of school-children in naturally fluoridated and nonfluoridated townships of Morayshire, Scotland." Community Dent Oral Epidemiol **30**(1): 70-9.

Takeda, T. and S. Takizawa (2008). Health Risks of Fluoride in the Chiang Mai Basin, Thailand. Groundwater Management in Asian Cities. Technology and Policy for Sustainability. S. Takizawa. Tokyo, Springer**:** pp301-327.

Tavener, J., R. M. Davies, et al. (2007). "Agreement amongst examiners assessing dental fluorosis from digital photographs using the TF index." Community Dent Health **24**(1): 21-5.

Taylor, A. M., R. P. Ellwood, et al. (2009). "Quantitative stain detection in vivo using fluorescent imaging." J Dent **37**(5): 397-405.

ten Bosch, J. J. (2000). Summary of reseach of Quantitative Light-induced Fluoresence. Early detection of dental caries II. Proceedings of the 4th Annual Indiana Conference, Indianapolis, Indiana University.

Thylstrup, A. and O. Fejerskov (1978). "Clinical appearance of dental fluorosis in permanent teeth in relation to histologic changes." Community Dent Oral Epidemiol **6**(6): 315-28.

Zohouri, F. V., A. Maguire, et al. (2006). "Sources of dietary fluoride intake in 6-7-year-old English children receiving optimally, sub-optimally, and non-fluoridated water." J Public Health Dent **66**(4): 227-34.

Table 6.1. Descriptive statistics for each cooking water interval for each of the metrics for fluorosis assessment.

		Photographic	Convex Hull Software			Existing Technique		
Cooking water intervals (ppm)		**TF index Score**	**Area**	**ΔF**	**ΔQ**	**Area**	**ΔF**	**ΔQ**
	N (%)							
<0.20	103 (18.6)	Mean 0.70 SD 0.93 Median 0 Range 0-5	Mean 0.1443 SD 0.1051 Median 0.0993 Range 0.0248-0.4635	Mean 0.0472 SD 0.0140 Median 0.0442 Range 0.0285-0.1234	Mean 0.0075 SD 0.0072 Median 0.0044 Range 0.0008-0.0329	Mean 0.0956 SD 0.0497 Median 0.0811 Range 0.0001-0.2269	Mean 2.3621 SD 0.4817 Median 2.2552 Range 1.2941-2.9831	Mean 0.2333 SD 0.1564 Median 0.2284 Range 0.0016-0.9463
0.2 to 0.59	111 (20.1)	Mean 1.01 SD 1.02 Median 1 Range 0-5	Mean 0.1808 SD 0.1303 Median 0.1534 Range 0.0233-0.5553	Mean 0.0479 SD 0.0132 Median 0.0444 Range 0.0297-0.0944	Mean 0.0098 SD 0.0097 Median 0.0073 Range 0.0073-0.0461	Mean 0.1097 SD 0.0542 Median 0.0991 Range 0.0001-0.2269	Mean 2.2643 SD 0.4554 Median 2.1827 Range 1.3557-2.3640	Mean 0.2571 SD 0.1660 Median 0.2284 Range 0.0016-0.9463
0.6 to 0.89	120 (21.7)	Mean 1.28 SD 1.30 Median 1 Range 0-7	Mean 0.2096 SD 0.1509 Median 0.1630 Range 0.0237-0.6348	Mean 0.0533 SD 0.0268 Median 0.0461 Range 0.0299-0.2309	Mean 0.0137 SD 0.0189 Median 0.0073 Range 0.0008-0.1456	Mean 0.1207 SD 0.0666 Median 0.1025 Range 0.0158-0.0305	Mean 2.3592 SD 0.5415 Median 2.2826 Range 1.4769-4.4142	Mean 0.3041 SD 0.2329 Median 0.2274 Range 0.0271-1.1500

0.9 to 1.59	108 (19.5)	Mean 1.65 SD 1.47 Median 1 Range 0-6	Mean 0.2516 SD 0.1616 Median 0.2060 Range 0.0390-0.6778	Mean 0.0572 SD 0.0189 Median 0.0523 Range 0.0299-0.2309	Mean 0.0168 SD 0.0163 Median 0.0101 Range 0.0013-0.0804	Mean 0.1328 SD 0.0650 Median 0.1287 Range 0.0039-0.2716	Mean 2.3923 SD 0.4940 Median 2.3307 Range 1.3235-3.8728	Mean 0.3325 SD 0.2051 Median 0.2825 Range 0.0059-0.8915
1.6+	111 (20.1)	Mean 2.30 SD 1.90 Median 2 Range 0-7	Mean 0.2991 SD 0.1791 Median 0.2929 Range 0.0245-0.7145	Mean 0.0616 SD 0.0263 Median 0.0557 Range 0.0297-0.2031	Mean 0.0219 SD 0.0223 Median 0.0162 Range 0.0007-0.1452	Mean 0.1547 SD 0.0754 Median 0.1500 Range 0.0012-0.3402	Mean 2.5921 SD 0.5821 Median 2.5000 Range 1.3450-4.6299	Mean 0.4235 SD 0.2886 Median 0.3588 Range 0.0017-1.3992
Total	553 (100)							

Table 6.2. Pairwise comparisons for water fluoride intervals from cooking water and Photographic TF scores, "convex hull" and Existing method outcomes.

Photographic TF Score			Convex hull software			Existing Technique		
Dependant Water interval			Dependant Water interval			Dependant Water interval		
0	1	0.02	0	1	0.11	0	1	0.24
	2	<0.001*		2	0.004*		2	0.036
	3	<0.001*		3	<0.001*		3	<0.001*
	4	<0.001*		4	<0.001*		4	<0.001*
1	0	0.02	1	0	0.11	1	0	0.24
	2	0.11		2	0.18		2	0.34
	3	<0.001*		3	<0.001*		3	0.005*
	4	<0.001*		4	<0.001*		4	<0.001*
2	0	<0.001*	2	0	0.004*	2	0	0.036
	1	0.11		1	0.18		1	0.34
	3	0.049		3	0.016		3	0.076
	4	<0.001*		4	<0.001*		4	<0.001*
3	0	<0.001*	3	0	<0.001*	3	0	<0.001*
	1	<0.001*		1	<0.001*		1	0.005*
	2	0.049		2	0.016		2	0.076
	4	0.01		4	0.11		4	0.027
4	0	<0.001*	4	0	<0.001*	4	0	<0.001*
	1	<0.001*		1	<0.001*		1	<0.001*
	2	<0.001*		2	<0.001*		2	<0.001*
	3	0.01		3	0.11		3	0.076

*

***difference considered significant at the 0.005 level**

Water Intervals: 0 = < 0.2ppm, 1 = 0.20-0.59ppm, 2 = 0.60-0.89ppm, 3 = 0.90-1.59ppm, 4 = 1.6+ppm

Table 6.3. Correlation coefficients for each of the analysis software metrics compared to photographic TF score (n=553)

Software Analysis Metric	**Spearman's rho**	
	Convex Hull Software	**Existing Technique**
Area	0.66**	0.59**
ΔF	0.54**	0.30**
ΔQ	0.65**	0.56**

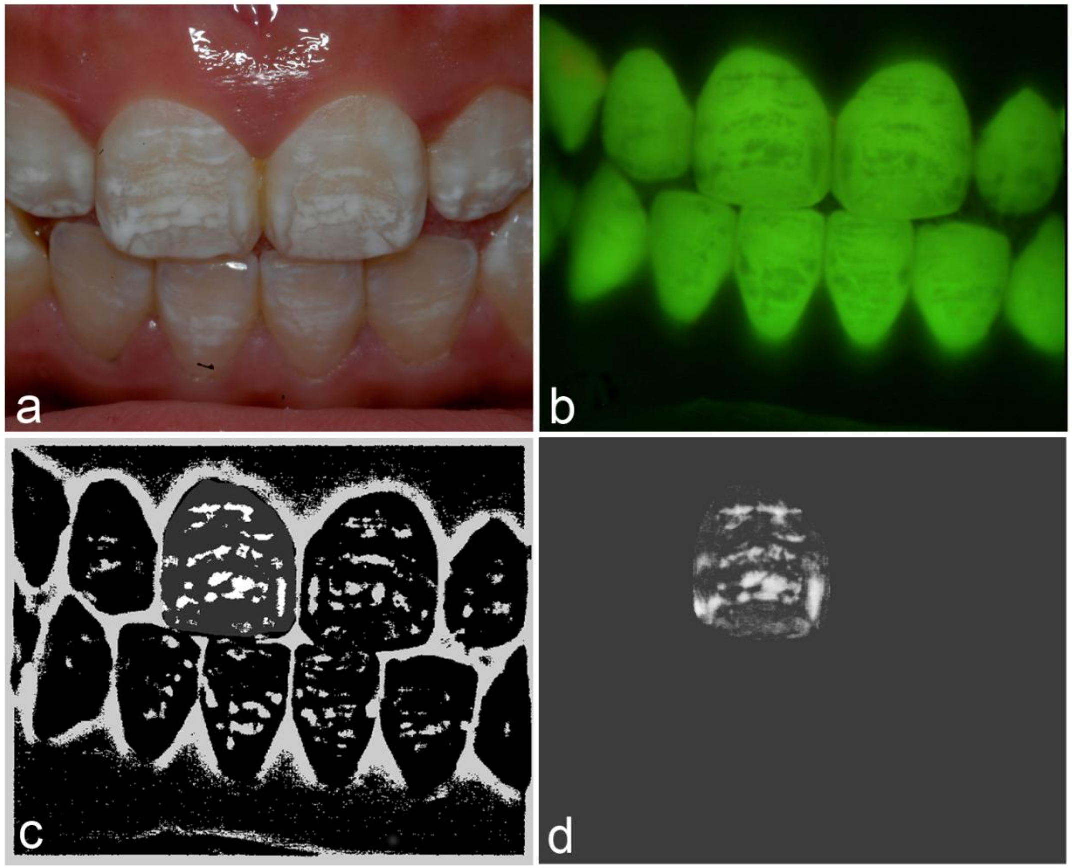
**** Correlation is significant at the 0.01 level (2-tailed)**

Table 6.4. ICC for software analysis techniques (n = 44).

Software Analysis Metric	Intra Class Correlation Coefficients	
	Convex Hull Software	**Existing Technique**
Area	0.84**	0.80**
ΔF	0.96**	0.75**
ΔQ	0.95**	0.85**

**** Correlation is significant at the 0.01 level (2-tailed)**

Figure 6.1. Images demonstrating fluorosis analysis



6.1a. Conventional digital image of a subject presenting with fluorosis.

6.1b. Fluorescence image captured demonstrating fluorosis (areas of florescence loss).

6.1c. Output from analysis using existing technique.

6.1d. Output from analysis using convex hull technique. (Image adjusted for contrast for illustrative purposes).

Figure 6.2. The photographic score demonstrating separation of the intervals for cooking water fluoride content, suggestive of a dose response. TF scores of 4 or higher have been grouped together as 4+.

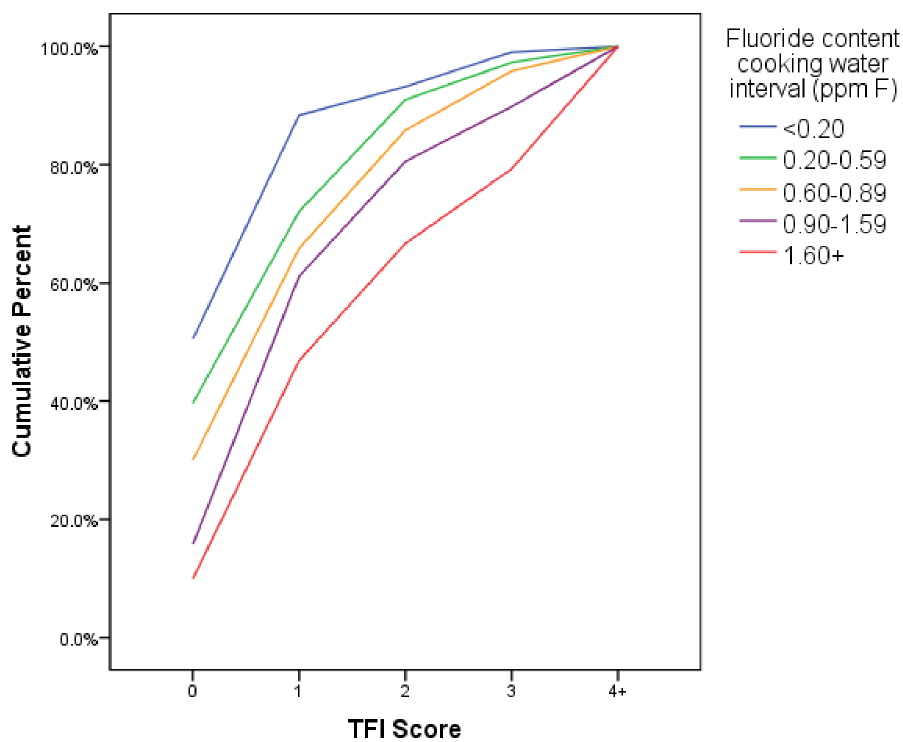


Figure 6.3. Boxplot with error bars (SD) for ΔQblur. Outliers (subject 837) highlighted.

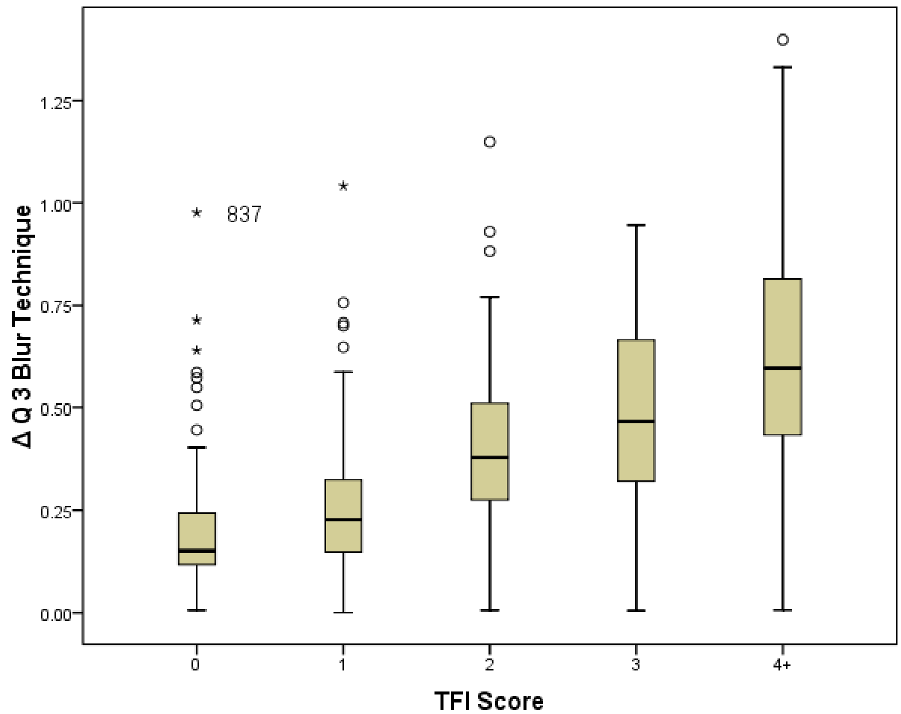


Figure 6.4. Boxplot with error bars (SD) for ΔQch. Outliers (subjects 837 and 230) highlighted.

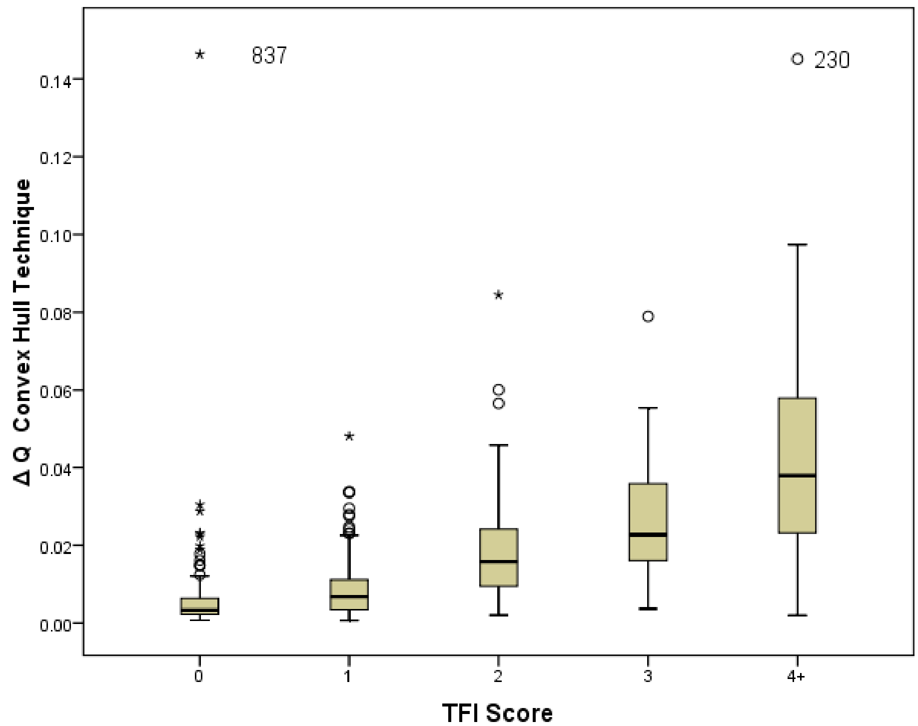
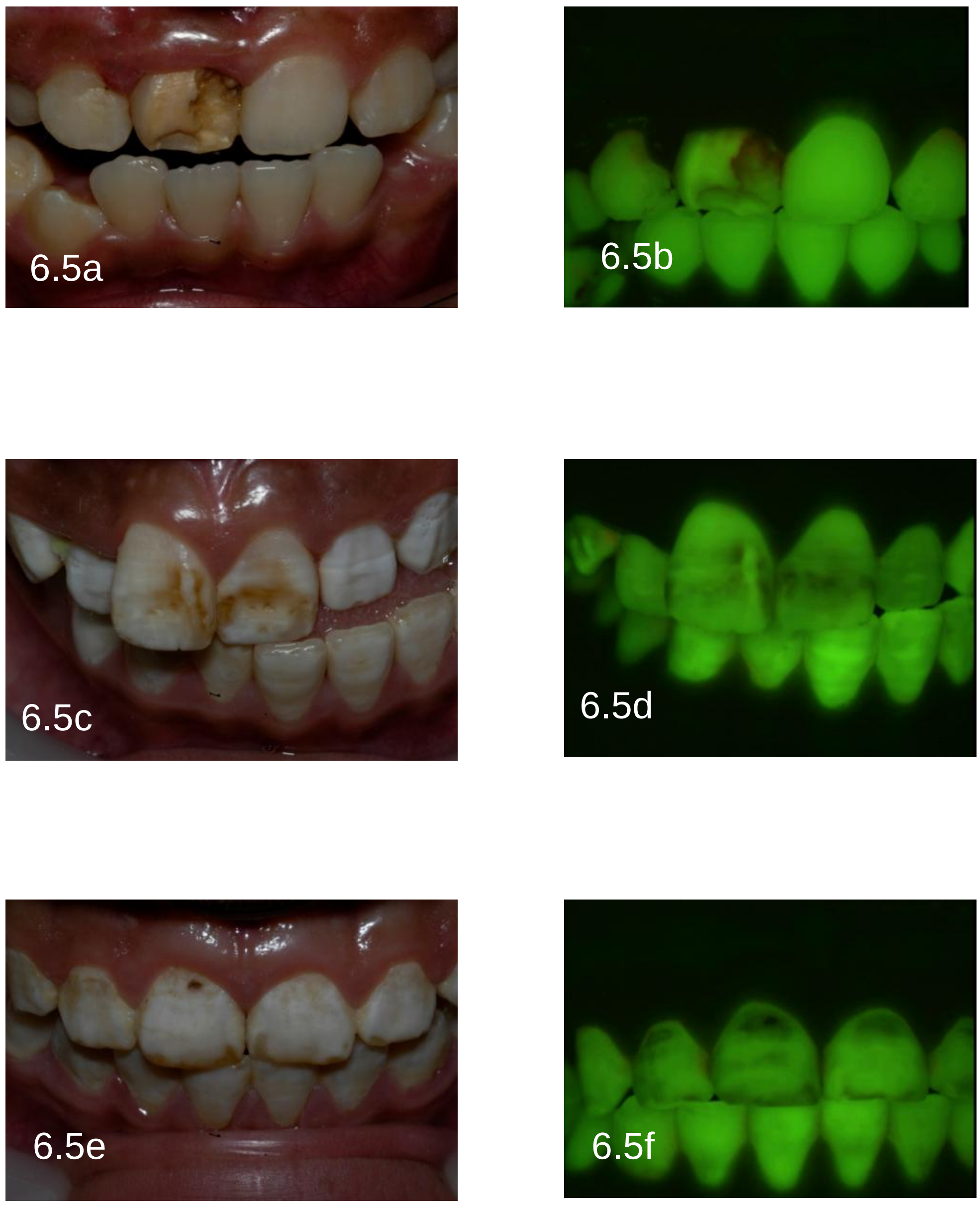


Figure 6.5. Images of subjects with confounding factors for QLF



6.5a. clinical photograph subject 837 presenting with non-fluorotic hypomineralization and enamel loss on maxillary right central incisor.

6.5b. QLF image of subject 837. Note the pattern of fluorescence loss on the maxillary right central incisor typical of enamel loss with possible caries. The areas in red indicate presence of plaque stagnation.

6.5c. Clinical photograph of subject 230 presenting with confluent areas of fluorosis with pitting and staining.

6.5d. QLF image of subject 230. Areas of fluorosis with stain exhibit greater fluorescence loss.

6.5e. Clinical photograph subject 545 presenting with confluent fluorosis and enamel loss and possible caries.

6.5f. QLF image of subject 545. Note the loss of fluorescence in the areas of enamel loss.

Chapter 7

Adolescent’s perception of the aesthetic impact of dental fluorosis in areas with and without water fluoridation

Adolescent's perception of the aesthetic impact of dental fluorosis in areas with and without water fluoridation

M. G. McGrady[1], R. P. Ellwood[2], M. Goodwin[1], N. Boothman[1], I. A. Pretty[2]

[1]School of Dentistry, University of Manchester, England
[2]Dental Health Unit, University of Manchester, England.

Running Head: Perceptions of Dental Fluorosis

Key Words: dental fluorosis, aesthetics, computer simulation, perception, photographs

Michael McGrady
StR/Honorary Lecturer in Dental Public Health
School of Dentistry
The University of Manchester
Higher Cambridge Street
Manchester
M13 9PL
Michael.mcgrady@manchester.ac.uk

Abstract

The use of fluorides for caries prevention is well established but is linked with an increased risk of dental fluorosis which may be considered to be aesthetically objectionable. Patient opinion should be considered when determining impact on aesthetics. The aim of this study was to assess subject perception of dental aesthetics of 11 and 12 year olds participating in an epidemiological caries and fluorosis survey in fluoridated and non-fluoridated communities in Northern England. Consented subjects were invited to rank in order of preference (appearance) a collage of 10 images on a touch-screen laptop. The photographs comprised an assortment of presentations of teeth that included white teeth, a spectrum of developmental defects of enamel and dental caries. Data were captured directly and exported into SPSS for analysis. Data were available for 1553 subjects. In general, there were no significant differences in the rank positions between the two cities, with the exception of teeth with caries and teeth with large demarcated opacities. Overall, there was a trend for teeth with fluorosis to be more tolerated in the fluoridated community; for TF 1 and TF 2 this preference was significant ($p<0.001$) The results of this study suggest teeth that are either very white have the highest preference but teeth with a fluorosis score of TF 1 may not be deemed unattractive to this population and age group. Images depicting teeth with caries or large demarcated opacities were deemed to be the least favoured. Subject preference of images depicting fluorosis falls with increasing severity of fluorosis.

Introduction

The use of fluorides in dentistry has been associated with a decline in the prevalence of dental caries through the use of optimally fluoridated community water supplies and fluoridated oral care products. However, the presence of multiple vehicles for fluoride delivery has also been associated with concerns regarding increased prevalence of dental fluorosis in both fluoridated and non-fluoridated communities (Clark 1994; Whelton, Crowley et al. 2004; Whelton, Crowley et al. 2006; Chankanka, Levy et al. 2010).

It has been demonstrated that exposure to fluoridated water supplies in addition to the use of fluoridated dentifrices is more effective than the use of fluoridated dentifrice alone in preventing caries (Whelton, Crowley et al. 2006). However, the increase in the prevalence of enamel fluorosis has led to concerns over the risk benefit ratio with respect to the use of fluorides to reduce caries and the risk of enamel fluorosis. In the UK, a systematic review commissioned by the government known as the York Report (NHS-CRD 2000) stated the occurrence of fluorosis at water fluoride levels of 1ppm was found to be high (predicted 48%, 95% CI 40 to 57). Of this fluorosis, the proportion considered to be aesthetically objectionable was lower (predicted 12.5%, 95% CI 7.0 to 21.5).

Studies addressing the aesthetic impact had taken place prior to the York Report (Hawley, Ellwood et al. 1996; Lalumandier and Rozier 1998). Teeth with Thylstrup and Fejerskov (TF) index scores of 3 were identified as eliciting concerns regarding appearance. This was in contrast to mild fluorosis (TF index 1 or 2) (Hawley, Ellwood et al. 1996). Dental fluorosis was deemed to be perceived as a potential aesthetic problem (Lalumandier and Rozier 1998) and despite the increase in prevalence of fluorosis it was not perceived by clinicians to be important to patients in less severe presentations (Bowen 2002). A recent review of the literature relating to fluorosis aesthetics and Oral Health Related Quality of Life (OHRQoL) concluded very mild and mild fluorosis was not associated with negative effects on OHRQoL, but more severe presentations of fluorosis was consistently reported less favourably (Chankanka, Levy et al. 2010).

It is probable there are differences in perception of aesthetics between clinicians and patients (Brisman 1980; Ellwood and O'Mullane 1995), but there is inconsistency in the literature with respect to this (Lalumandier and Rozier 1998). However, this does not take into consideration the different social norms and beliefs between the various study populations that could have an impact upon the outcome of perception of aesthetics, nor does it reconcile the desire to record clinically significant or aesthetically objectionable fluorosis with the need to record all forms of fluorosis for epidemiological purposes.

Nevertheless, a report from the Medical Research Council (UK) (MRC 2002) that followed the York Report added a further qualification on the viewpoint of the aesthetic component of fluorosis by stating:

> *"Further studies should determine the public's perception of dental fluorosis with particular attention to the distinction between acceptable and aesthetically unacceptable fluorosis."*

The ability of a group of lay persons to reliably comment upon the aesthetic appearance of fluorosis is difficult to assess. Research had shown agreement between groups that included lay people reduced as the TF score (severity of fluorosis) increased (Riordan 1993).

Studies have highlighted the effects of facial features, viewing distance and tooth morphology and alignment as factors that can influence an individual's perception of aesthetics (McKnight, Levy et al. 1999; Levy, Warren et al. 2002; Edwards, Macpherson et al. 2005). The display media employed may also have an effect on a viewer's capacity to rate images with image magnification, and ambient lighting acting as confounding factors. Whilst standardized techniques can be used to capture images, the decision to capture images of wet or dry teeth will have an effect on the degree of hypomineralization that is recorded.

The aim of this study was to evaluate subject perception of dental aesthetics. The main focus was the perception of aesthetics relating to enamel fluorosis in selected populations residing in fluoridated and non-fluoridated urban communities.

Subjects and Methods

Subjects were males and females aged 11 to 13 who were participating in an epidemiological survey of caries and fluorosis prevalence and severity in an urban population with water fluoridation (Newcastle Upon Tyne, UK) and without (Greater Manchester, UK). Ethical approval was obtained from the University of Manchester Committee on the Ethics of Research on Human Beings (ref: 07952) to include the subject assessment of fluorosis aesthetics. Written informed consent was obtained from the subjects following an opportunity for parents to object to their child's participation via a postal return of pre-prepared slips.

In order to obtain balance between the two cities with respect to social deprivation, schools were initially targeted based upon the percentage Free School Meals Entitlement (%FSME). The %FSME data was obtained through the schools and Local Authorities and has been used as a variable for estimating social deprivation in resource allocation for schools in Northern Ireland (Shuttleworth 1995). During recruitment the subjects provided postcode details that were used to obtain Index of Multiple Deprivation (IMD) scores. Eligible subjects were required to be lifelong residents in their geographical location (self reported).

Recruited subjects were asked to complete a brief computer based assessment of tooth aesthetics. The assessment comprised of a montage of ten images of teeth with a variety of dental conditions which the subjects were asked to rate in order of preference with respect to appearance (Figure 7.1). The images were computer simulated images with "stencils" of dental conditions overlaid onto a base image of an individual's teeth. This ensured the size and contour of the teeth as well as the lips and gingival tissues were consistent across the images. Every subject used the same computer to ensure the image size and the viewing distances were consistent for each subject. The ten images are illustrated and described in Figure 7.1.

The images were loaded into a programme written in Microsoft Visual Studio (Microsoft Corp, Seattle, USA) running on an IBM ThinkPad (Lenovo X60). Each subject was invited to enter their unique subject identifier into the computer which then displayed the ten images in a randomized order on the screen. The subjects were asked to independently rate the images in order of preference by dragging a number between 1 and 10 to the images using a touchscreen pen. The subjects were free to alter their preferences by relocating the numbers between the images. Once the subjects were satisfied with their selection they were asked to save their preferences which downloaded the information to a database and exited the programme in readiness for the next subject.

The database was exported to SPSS for analysis. The mean ranks were calculated for each of the images and analysis performed to explore patterns in the data with respect to fluoridation status, deprivation and gender by performing t-tests between data generated between the two cities and non-parametric pairwise comparisons of rankings for the images to explore image preference.

Results

In total, data for 1553 subjects were available for analysis. Demographics for the subjects are described in Table 7.1. Descriptive statistical analysis provided mean image ranks for Newcastle (fluoridated), Manchester (non-fluoridated) and for all subjects and are displayed in Table 7.2. Overall, subjects expressed the highest preference for very white teeth and teeth Vita shade A1. Images of teeth with caries or large demarcated opacities demonstrated the least preference. Teeth with a fluorosis severity of TF1 had an overall rank position of third. However, there was no clear pattern of preference amongst the remaining images with clustering of mean ranks and greater variability. In general, there were no differences in the rank positions between the two cities, with the exception of the rank positions of teeth with caries (Figure 7.1j) and teeth with large demarcated opacities (Figure 7.1h) which were ranked 9 and 10 in Newcastle but in Manchester caries and large demarcated opacities were ranked 10 and 9 respectively. Similarly, the rankings of teeth with a chipped incisal edge (Figure 1i) and teeth with fluorosis score TF2 (Figure 7.1d) are reversed between the two cities. Comparison of the mean ranks for each image between the two cities revealed significant differences for images of teeth with fluorosis severities TF1 and TF2 (Figure 7.1c, and 7.1d respectively). There were also significant differences between the cities for images of teeth with caries and teeth with a chip in the incisal edge. This is also displayed in Table 7.1. A scatter plot of the mean image ranks for the two cities is illustrated in Figure 7.2. The scatter plot reveals the differences in mean image ranks for teeth with fluorosis have a lower rank in fluoridated Newcastle than non-fluoridated Manchester i.e. fluorosis appears to be considered more aesthetically acceptable in Newcastle. Caries was preferred less by subjects in Newcastle compared to subjects in Manchester.

To explore the effect of deprivation on aesthetics perception, the mean image ranks for all subjects in the lowest and highest quartiles of deprivation (as determined by Index of Material Deprivation) were compared and shown in Table 7.2. After performing probability corrections to account for multiple comparisons, significant differences for teeth with medium demarcated opacities (p=0.001) and teeth with a chip in the incisal edge (p=0.001) were found between subjects from the lowest and highest quartiles of deprivation. A scatter plot of the mean ranks for the images and deprivation is illustrated in Figure 7.3. The data suggests teeth with a medium demarcated opacity are deemed more acceptable to subjects who are more deprived and teeth with a chip in the incisal edge are deemed more acceptable to less deprived subjects.

There were no significant differences in mean image ranks when looking at data for gender in this population.

A binomial analysis was carried out exploring pair-wise comparisons between each of the images to determine which image was preferred over the other. Selected data from this analysis is displayed in Table 7.3 for very white teeth and for teeth with a fluorosis score of TF1. The data clearly illustrates subjects significantly preferred very white teeth compared to all of the other images. When exploring the data for teeth with a fluorosis score of TF1, subjects did not prefer TF1 to teeth shade A1 or very white teeth. A majority of subjects preferred TF1 to teeth with a medium sized demarcated opacity but this preference was not statistically significant (p = 0.182). Teeth with a fluorosis score of TF1 were significantly preferred over all remaining images.

Discussion

The results of this study suggest teeth that are very white have the highest preference but teeth with a fluorosis score of TF 1 may not be deemed unattractive to this population and age group. The very white teeth represented an unnatural presentation that could only be achieved by cosmetic procedures. Unsurprisingly, images depicting teeth with caries or large demarcated opacities were deemed to be the least favoured. This is consistent with previous work related to dental aesthetics (Cunliffe and Pretty 2009; Browne, Whelton et al. 2011). The remaining images provided an equivocal representation of subject preference. This is not an unusual finding with ranked data where there is a clear separation at extreme ends of the scale for the most and least preferred images and where there remains a central group of images that subjects have no strong preference of one image over another. The finding that teeth with a chip in the incisal edge were deemed more acceptable by subjects who are less deprived is of interest. However, it is difficult to provide a satisfactory explanation for this phenomenon as additional contextual information was not available. For example, it was not known if a subject's decision was influenced by factors such as the effect routine restorative treatment would have on the appearance of the teeth. Consequently this image was associated with the largest standard deviation of mean rank position i.e. the most uncertainty and variation. It is important to recognize the outcome of this study was to explore subject preference, not to establish a level of aesthetically objectionable fluorosis. However, when considering comparisons between the two cities it is clear when location (fluoridation status) is a factor. Subjects have more difficulty expressing preference when assessing images with fluorosis severities of TF1 and TF2 in terms of preference when compared to TF3. This might suggest when fluorosis severity reaches threshold of TF3 subjects more reliably express a lower preference.

It should, however, be stated there are several limitations with the study design and there are issues to be raised from the interpretation of the data. The nature of the study assessment, a brief computer-based questionnaire, is not a novel technique and has been used successfully and reported elsewhere in the literature (McKnight, Levy et al. 1999; Levy, Warren et al. 2002; Edwards, Macpherson et al. 2005). However the outcomes of the current study were limited to simple ranking data, associated with limitations and difficulties in analysis and interpretation as the numeric output has more limited value in analytical terms. Additional work may be undertaken to examine the use of “ties” between rating and Likert scales – although these approaches also have their limitations.

The subjects who participated in the survey were self-reported lifetime residents of their locality. Therefore this analysis does not take into consideration the aesthetic perceptions of individuals who moved into a particular location. These data suggest subjects who were lifetime residents in a fluoridated region may tolerate or perceive mild levels of fluorosis more favourably than individuals residing in a non-fluoridated area. Is this a phenomenon resulting from social norms and would an individual who moves from a non-fluoridated region into a fluoridated region hold the same views? Similarly, this study has not taken into account possible effects of subject ethnicity on aesthetic perception. Both of these should be considered for future work – perhaps concentrating on smaller subject numbers and a more qualitative approach.

Whilst the remit of this study was to investigate subject perception of tooth aesthetics, particularly fluorosis, it is important the make a distinction between fluorosis prevalence and severity as determined by a dental professional and what is considered to be fluorosis of aesthetic concern from the perspective of a patient. The latter is an important factor in fully determining the impact of the risk benefit ratio of an intervention such as water fluoridation or the use of fluoridated oral care products. However, it is necessary to consider all presentations of fluorosis from an epidemiological standpoint particularly when identifying trends or changes in fluorosis prevalence and severity. The choice of index employed during the assessment of fluorosis has a bearing on the determination of the prevalence and severity of fluorosis. An index which requires the drying of teeth prior to scoring such as the TF Index will result in the dehydration of hypomineralized enamel and a change in refractive index. Hence minor fluorotic opacities may not be visible when teeth are viewed wet. As a result of this phenomenon the results of this study represent an artificial scenario whereby subjects are being asked to rate preference of teeth viewed as if they had been dried. It would be interesting to note any changes to subject perception if the teeth had been viewed as they would appear wetted by saliva.

In order to control the experimental environment, measures were taken to remove confounding factors. The use of a standardized base image removed the effects of tooth morphology and surrounding facial features that could impact on aesthetic perception. However, this resulted in the subjects being asked to rate only a single presentation of each type of condition. It stands to reason that different presentations of conditions could be rated differently within their classification (e.g. differing presentations of TF 2) or between images of fluorosis and different classifications such as caries or demarcated opacities. The subjects also viewed images at a life size level of magnification and this was consistent throughout the study. It has already been shown in the literature that both the image magnification, the image viewing distance and the presence of other facial features has an impact of aesthetic perception (Edwards, Macpherson et al. 2005).

It is clear from the results of this study that subjects have a preference for white, blemish free teeth, even within this age group, many of which are still in the mixed dentition stage. The inference from the data is mild forms of fluorosis (TF 1) do not appear to be associated with aesthetic issues. As fluorosis severity increases, the level of acceptance declines which is in agreement with earlier work (Hawley, Ellwood et al. 1996; Tabari, Ellwood et al. 2000; Edwards, Macpherson et al. 2005; Tavener, Davies et al. 2007; Browne, Whelton et al. 2011). However, it is not possible from the outcome of this study to determine a cut off level of fluorosis severity that is considered to be an aesthetic problem.

Acknowledgements

The authors wish to thank the pupils and staff at the schools who participated and Dianne Tabari, Deborah Howe and Valerie Dalton from Newcastle Primary Care Trust for their support and assistance during this project. The images used during the study were provided by Dr Jacqueline Tavener and the computer program created by Dr Andrew Taylor of the Dental Health Unit. Dr Pretty is funded by a Clinician Scientist Award from the National Institute for Health Research (UK). This research was supported by Colgate Palmolive Dental Health Unit, Manchester, UK.

References

Bowen, W. H. (2002). "Fluorosis: Is it really a problem?" J Am Dent Assoc **133**(10): 1405-1407.

Brisman, A. S. (1980). "Esthetics: a comparison of dentists' and patients' concepts." J Am Dent Assoc **100**(3): 345-52.

Browne, D., H. Whelton, et al. (2011). "The aesthetic impact of enamel fluorosis on Irish adolescents." Community Dentistry and Oral Epidemiol **39**(2): 127-136.

Chankanka, O., S. M. Levy, et al. (2010). "A literature review of aesthetic perceptions of dental fluorosis and relationships with psychosocial aspects/oral health-related quality of life." Community Dent Oral Epidemiol **38**(2): 97-109.

Clark, D. C. (1994). "Trends in prevalence of dental fluorosis in North America." Community Dent Oral Epidemiol **22**(3): 148-52.

Cunliffe, J. and I. Pretty (2009). "Patients' ranking of interdental "black triangles" against other common aesthetic problems." Eur J Prosthodont Restor Dent **17**(4): 177-81.

Edwards, M., L. M. Macpherson, et al. (2005). "An assessment of teenagers' perceptions of dental fluorosis using digital simulation and web-based testing." Community Dent Oral Epidemiol **33**(4): 298-306.

Ellwood, R. P. and D. O'Mullane (1995). "Enamel opacities and dental esthetics." J Public Health Dent **55**(3): 171-6.

Hawley, G. M., R. P. Ellwood, et al. (1996). "Dental caries, fluorosis and the cosmetic implications of different TF scores in 14-year-old adolescents." Community Dent Health **13**(4): 189-92.

Lalumandier, J. A. and R. G. Rozier (1998). "Parents' satisfaction with children's tooth color: fluorosis as a contributing factor " J Am Dent Assoc **129**(7): 1000-1006.

Levy, S. M., J. J. Warren, et al. (2002). "Follow-up study of dental students' esthetic perceptions of mild dental fluorosis." Community Dent Oral Epidemiol **30**(1): 24-8.

McKnight, C. B., S. M. Levy, et al. (1999). "A pilot study of dental students' esthetic perceptions of computer-generated mild dental fluorosis compared to other conditions." J Public Health Dent **59**(1): 18-23.

MRC (2002). Medical Research Council Working Group Report. Water fluoridation and health. London, MRC.

NHS-CRD (2000). A Systematic Review of Public Water Fluoridation. York, The University of York, NHS Centre for Reviews and Dissemination (Report 18).

Riordan, P. J. (1993). "Perceptions of dental fluorosis." J Dent Res **72**(9): 1268-74.

Shuttleworth, I. (1995). "The Relationship between Social Deprivation, as Measured by Individual Free School Meal Eligibility, and Educational Attainment at GCSE in Northern Ireland: A Preliminary Investigation." British Educational Research Journal **21**(4): 487-504.

Tabari, E. D., R. Ellwood, et al. (2000). "Dental fluorosis in permanent incisor teeth in relation to water fluoridation, social deprivation and toothpaste use in infancy." Br Dent J **189**(4): 216-20.

Tavener, J., R. M. Davies, et al. (2007). "Agreement amongst examiners assessing dental fluorosis from digital photographs using the TF index." Community Dent Health **24**(1): 21-5.

Whelton, H., E. Crowley, et al. (2006). "Dental caries and enamel fluorosis among the fluoridated population in the Republic of Ireland and non fluoridated population in Northern Ireland in 2002." Community Dent Health **23**(1): 37-43.

Whelton, H., E. Crowley, et al. (2004). "Dental caries and enamel fluorosis among the fluoridated and non-fluoridated populations in the Republic of Ireland in 2002." Community Dent Health **21**(1): 37-44.

Table 7.1. Subject demographics

City	Total Subjects	Males	Females	Mean Age Years (SD)
Newcastle	741	367	374	12.66 (0.44)
Manchester	812	471	341	12.33 (0.65)
	1553	838	715	

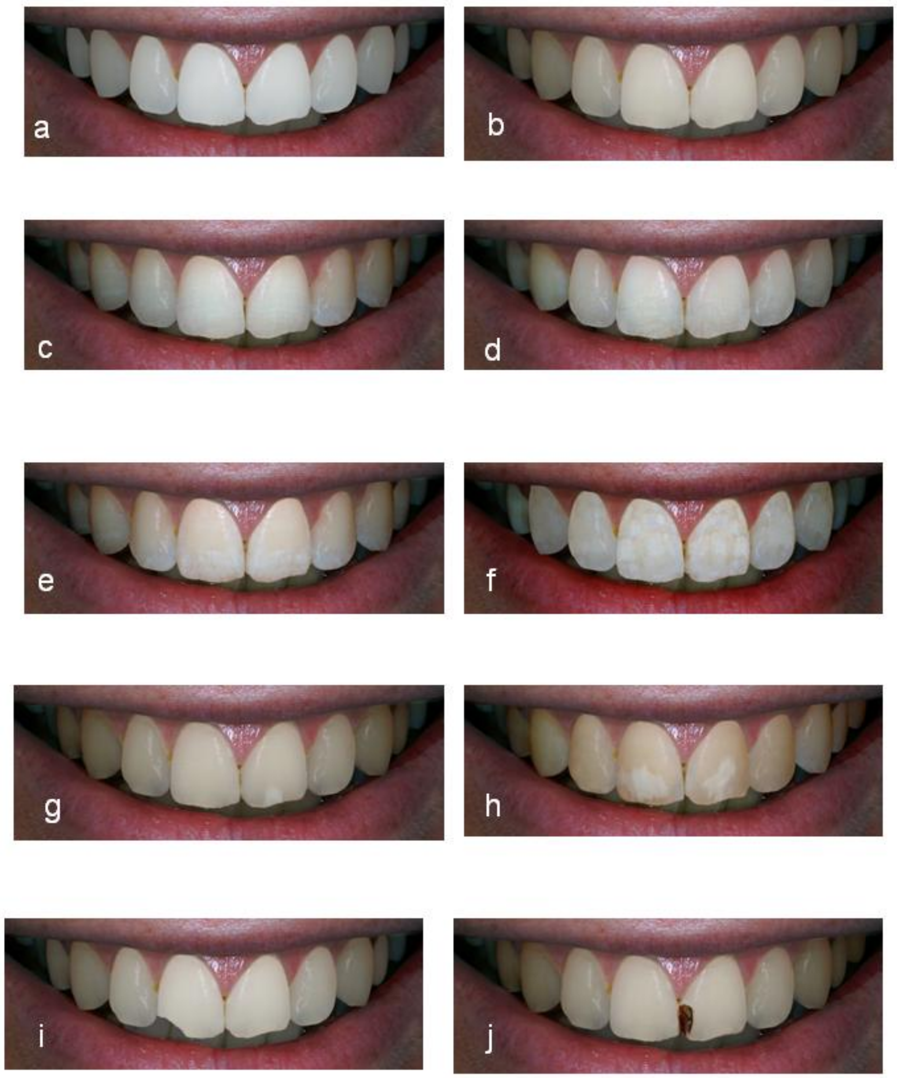
Table 7.2. Descriptive analysis: for all subjects, by city and for the lowest and highest quartiles of deprivation.

	City					Deprivation			
	Newcastle (N= 741) Fluoridated	Manchester (N = 812) Non-fluoridated	Total (1553)	Independent Samples t-test (between cities)		Lowest Quintile Deprivation (n = 308)	Highest Quintile Deprivation (n = 325)	Independent Samples t-test (between deprivation quintiles)	
				P value	95% CI			P value	95% CI
	Mean (S.D.)	Mean (S.D.)	Mean (S.D.)			Mean (S.D.)	Mean (S.D.)		
Very White Teeth	1.07 (0.452)	1.07 (0.536)	1.07 (0.497)	ns		1.10 (0.689)	1.09 (0.612)	ns	
Vita shade A1	2.32 (0.945)	2.34 (1.031)	2.33 (0.991)	ns		2.38 (1.089)	2.40 (1.006)	ns	
Fluorosis TF1	4.17 (1.529)	4.47 (1.618)	4.33 (1.583)	< 0.001	(- 0.451, - 0.137)	4.23 (1.556)	4.37 (1.640)	ns	
Medium demarcated opacity	4.55 (1.547)	4.48 (1.665)	4.51 (1.61)	ns		4.21 (1.514)	4.62 (1.705)	0.001	(- 0.633, - 0.158)
Fluorosis TF2	5.22 (1.620)	5.54 (1.678)	5.39 (1.658)	< 0.001	(- 0.485, - 0.156)	5.55 (1.557)	5.36 (1.733)	ns	
Vita A1 chipped incisal edge	5.75 (2.28)	5.43 (2.285)	5.59 (2.287)	< 0.005	(0.01, 0.554)	5.92 (2.365)	5.30 (2.223)	0.001	(0.253, 0.969)
Fluorosis TF3	6.63 (1.512)	6.81 (1.504)	6.72 (1.51)	ns		6.60 (1.497)	6.77 (1.511)	ns	
Fluorosis TF4	7.92 (1.453)	7.99 (1.639)	7.95 (1.553)	ns		8.02 (1.486)	7.99 (1.476)	ns	
Large demarcated opacity	8.58 (1.395)	8.47 (1.523)	8.52 (1.464)	ns		8.38 (1.513)	8.63 (1.484)	ns	
Teeth with Caries	8.79 (1.614)	8.41 (1.901)	8.59 (1.78)	< 0.001	(0.203, 0.556)	8.61 (1.836)	8.46 (1.855)	ns	

Table 7.3. Binomial pairwise comparisons: depicting image preference for very white teeth and teeth with fluorosis severity TF1 against each image.

	First group	Second group	Asymp. Sig. (2-tailed)
Very white vs A1	1494	59	<0.001
Very white vs TF1	1537	16	<0.001
Very white vs Medium DO	1544	9	<0.001
Very white vs TF2	1545	8	<0.001
Very white vs A1 chip	1549	4	<0.001
Very white vs TF3	1547	6	<0.001
Very white vs TF4	1549	4	<0.001
Very white vs Large DO	1549	4	<0.001
Very white vs caries	1549	4	<0.001
	First group	Second group	Asymp. Sig. (2-tailed)
TF1 vs Very white	16	1537	<0.001
TF1 vs A1	182	1371	<0.001
TF1 vs Medium DO	804	749	= 0.171
TF1 vs TF2	1119	434	<0.001
TF1 vs A1 chip	966	587	<0.001
TF1 vs TF3	1359	194	<0.001
TF1 vs TF4	1459	94	<0.001
TF1 vs Large DO	1484	69	<0.001
TF1 vs caries	1420	133	<0.001

Figure 7.1. Images selected for study. Note how the images share a common base image with conditions stencilled over.



7.1a: very white teeth; 7.1b: teeth shade A1; 7.1c teeth with fluorosis TF1; 7.1d: teeth with fluorosis TF2; 7.1e: teeth with fluorosis TF3; 7.1f: teeth with fluorosis TF4; 7.1g: teeth with a medium demarcated opacity on one tooth teeth; 7.1h: teeth with large demarcated opacities on both central incisors; 7.1i: teeth shade A1 with a chip on incisal edge; 7.1j: teeth with carious lesion

Figure 7.2. Mean rank for each image for both cities demonstrating level of agreement of subjects between cities suggesting subjects in Newcastle are more tolerant of milder presentations of fluorosis compared to Manchester.

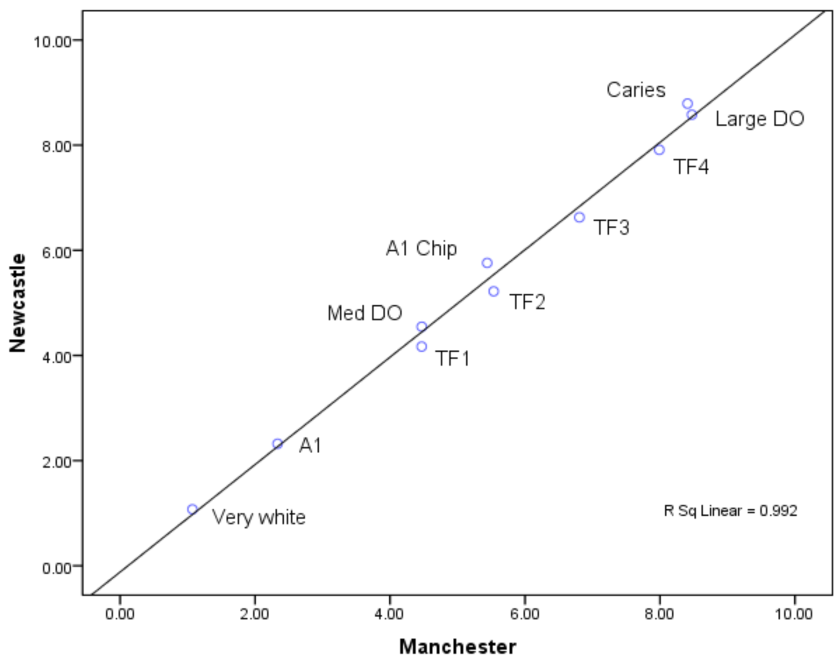
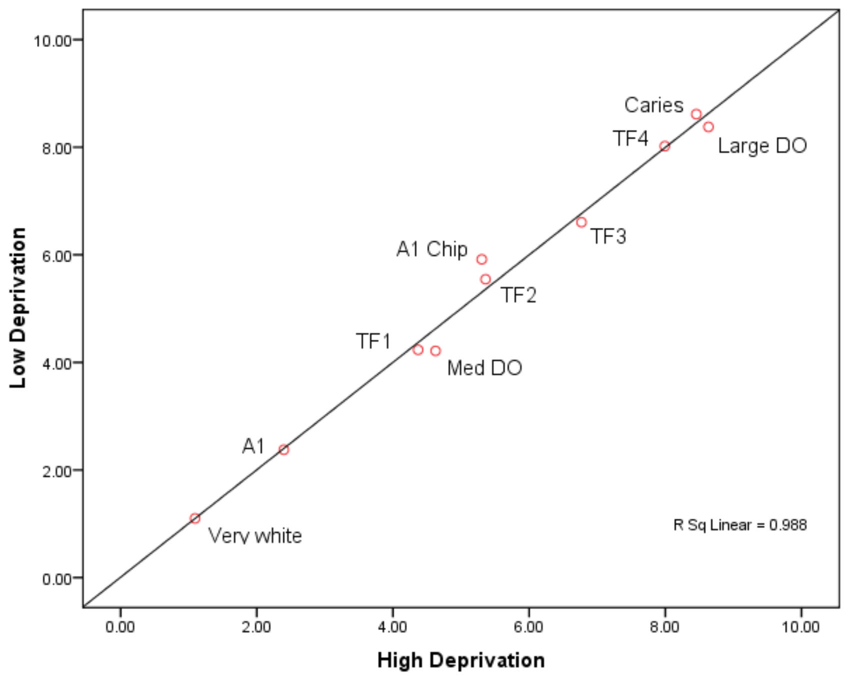


Figure 7.3. Mean rank for each image (all subjects) for the lowest and highest quintiles of deprivation.



Chapter 8

The Effect of Social Deprivation on the Prevalence and Severity of Dental Caries and Fluorosis in Populations with and without Water Fluoridation.

The Effect of Social Deprivation on the Prevalence and Severity of Dental Caries and Fluorosis in Populations with and without Water Fluoridation.

M. G. McGrady[1], R. P. Ellwood[2], A. Maguire[3], M. Goodwin[1], N. Boothman[1], I. A. Pretty[2]

[1]School of Dentistry, University of Manchester, England
[2]Colgate Palmolive Dental Health Unit, University of Manchester, England.
[3]School of Dental Sciences, University of Newcastle, England.

Corresponding Author:

Michael G McGrady

Room 1.030 Coupland 3 Building
School of Dentistry
The University of Manchester
Higher Cambridge Street
Manchester
M13 9PL

Abstract

*Objectives***:** To determine the effect of social deprivation on the prevalence of caries (including caries lesions restricted to enamel) and enamel fluorosis in areas that are served by either fluoridated or non-fluoridated drinking water. To evaluate the ability of clinical scoring, remote blinded, photographic scoring for caries and fluorescence imaging for fluorosis to detect any differences between these populations.

Methods: Subjects were male and female lifetime residents aged 11-13 years. Clinical assessments of caries and fluorosis were performed on permanent teeth using ICDAS and blind scoring of standardized photographs of maxillary central incisors using TF Index.

Results: Data from 1783 subjects were available (910 Newcastle, 873 Manchester). Levels of material deprivation (Index of Multiple Deprivation) were comparable for both populations (Newcastle mean 35.22, range 2.77-78.85; Manchester mean 37.04, range 1.84-84.02). Subjects in the fluoridated population had significantly less caries experience than the non-fluoridated population when assessed by clinical scores or photographic scores across all quintiles of deprivation for white spot lesions: Newcastle mean DMFT 2.94 (clinical); 2.51 (photo), Manchester mean DMFT 4.48 (clinical); 3.44 (photo) and caries into dentine (Newcastle Mean DMFT 0.65 (clinical); 0.58 (photo), Manchester mean DMFT 1.07 (clinical); 0.98 (photo). The only exception being for the least deprived quintile for caries into dentine where there were no significant differences between the cities: Newcastle mean DMFT 0.38 (clinical); 0.36 (photo), Manchester mean DMFT 0.45 (clinical); 0.39 (photo). The odds ratio for white spot caries experience (or worse) in Manchester was 1.9 relative to Newcastle. The odds ratio for caries into dentine in Manchester was 1.8 relative to Newcastle. The odds ratio for developing fluorosis in Newcastle was 3.3 relative to Manchester.

Conclusions: Water fluoridation appears to reduce the social class gradient between deprivation and caries experience when considering caries into dentine. However, this was associated with an increased risk of developing fluorosis. The use of intra-oral cameras and remote scoring of photographs for caries demonstrated good potential for blinded scoring.

Introduction

In the second half of the 20th Century water fluoridation schemes were introduced in several countries around the world in order to address the high prevalence of dental caries. The schemes were implemented following expansive research by H Trendley Dean in the United States (Dean 1938; Dean, Arnold et al. 1942; Dean, Arnold et al. 1950). In the United Kingdom during the 1950's, following observation on the schemes in the United States, several pilot water fluoridation schemes were introduced in order to evaluate water fluoridation as a public health measure. Ultimately, the only major UK localities still covered by fluoridation schemes are the West Midlands and Newcastle upon Tyne.

There have been numerous studies evaluating the use of water fluoridation schemes. In the Netherlands, a major longitudinal study investigated the effects of fluoridating the water supply of Tiel and comparing the patterns of caries prevalence and severity with non-fluoridated Culemborg. The study ran from 1953 until 1971 and found differences between the localities in caries severity with significantly fewer white spot lesions in Tiel progressing into cavitated lesions compared to non-fluoridated Culemborg (Backer Dirks, Houwink et al. 1961; Kwant GW, Houwink B et al. 1973; Groeneveld 1985; Groeneveld, Van Eck et al. 1990).

Similar studies in the UK have demonstrated reductions in caries in populations following the introduction of water fluoridation (HMSO 1962; HMSO 1969). Studies conducted in Newcastle and non-fluoridated Northumberland demonstrated similar differences in caries levels between the two populations when compared to studies conducted elsewhere in the UK (Jackson, James et al. 1975; Rugg-Gunn AJ, Carmichael CL et al. 1977; French, Carmichael et al. 1984; Murray, Gordon et al. 1984; Jackson, James et al. 1985; Rugg-Gunn, Carmichael et al. 1988). When fluoridation schemes have ended, as in the case of Anglesey where capital investment for new equipment was deemed economically unviable, it has been demonstrated that caries levels increase following cessation of fluoridation (Hulse, Kenrick et al. 1995).

As the advent of fluoridated dentifrices became increasingly popular during the 1970's and 1980's, the differences between fluoridated and non-fluoridated populations reduced.

Caries prevalence declined in both fluoridated and non-fluoridated populations and whilst there were still significant differences between caries levels in fluoridated and non-fluoridated populations, the differences were no longer as great as they had been during the 1950's and 1960's. In addition to this, there had been an increase in the prevalence of fluorosis (Whelton, Crowley et al. 2004). Furthermore, owing to confounding factors such as halo effects and identifying sources of fluoride, it has become more difficult to investigate the impact of water fluoridation over and above the use of fluoridated dentifrice alone (Horowitz 1996; Zohouri, Maguire et al. 2006; Maguire, Zohouri et al. 2007).

The link between social deprivation and ill health has been known for many years (DHSS 1980; Macintyre 1997). This is also reflected in oral health where despite overall reductions in caries levels there are still persistent inequalities between the social classes (Watt and Sheiham 1999). Studies conducted in the UK have shown differences in child caries levels between areas of high and low deprivation including comparisons between fluoridated and non-fluoridated populations suggesting water fluoridation may reduce inequalities in health relating to dental caries by reducing the social gradient (Carmichael, Rugg-Gunn et al. 1980; Carmichael, French et al. 1984; Carmichael, Rugg-Gunn et al. 1989; Ellwood and O'Mullane 1994; Ellwood and O'Mullane 1995; Jones and Worthington 1999; Riley, Lennon et al. 1999; Jones and Worthington 2000; Ellwood, Davies et al. 2004).

There are several means of measuring deprivation within a population and data are generally reported as summary measures to assist in the exploration of other dependent variables. Two commonly used indices in dental research are Townsend's Index of Material Deprivation (Townsend, Phillimore et al. 1988) and the Jarman Deprivation Score (Jarman 1983). More recently, the Index of Multiple Deprivation (IMD) has become popular as a means of reporting deprivation at a Local Super Output Area (LSOA) level (Noble, McLennan et al. 2008). The IMD has seven domains with indicators in each domain that are measured separately. The seven domains are: income, employment, health, education (skills and training), barriers to housing, crime and living environment. A weighting of these seven domains provides an overall area level aggregate score.

The York Report (NHS-CRD 2000) concluded "the evidence of a benefit of a reduction in caries should be considered together with the increased prevalence of dental fluorosis." Certain aspects within the evidence base needed addressing to improve quality. Consideration should be given to increases in prevalence of dental fluorosis where evidence showed a benefit of a reduction in dental caries. The report also stated the evidence base required improvement relating to potential harm or the impact on social inequalities. Another report followed from the Medical Research Council (MRC) that echoed the views of the York report relating to the need to improve the evidence base (MRC 2002). The MRC report recommended appropriate measures of social inequalities were needed for research focused on water fluoridation, dental caries and fluorosis.

As caries levels have declined, the need for more sensitive methods of detection has increased. In the UK the British Association for the Study of Community Dentistry (BASCD) has conducted a series of national surveys relating to dental health (now known as the NHS Dental Epidemiology Programme (DEP)). Traditionally the survey has employed the use of the DMF index using trained examiners following criteria defined for the age group in question. The "D" or decayed component employed by BASCD uses a diagnostic threshold of visual caries into dentine (D_3). Whilst this has been a useful means for screening and surveillance it is now questionable if assessing caries at this threshold will be acceptable for the future when assessing the impact of preventative measures associated with a need to detect early carious lesions (Pitts, Evans et al. 1997; Pitts 2001; Pitts 2004; Pretty 2006). There is a need to develop reliable means of detecting and monitoring early carious lesions.

The International Caries Detection and Assessment System (ICDAS) was developed to define visual caries detection criteria at an early non-cavitated stage that could inform diagnosis, prognosis and clinical management (Pitts 2004; Ismail, Sohn et al. 2007). The criteria for ICDAS codes are detailed in **Appendix 1** of this thesis). The ability of the ICDAS system to enable detection of early, non-cavitated (white spot) lesions provides an opportunity to explore caries prevalence in fluoridated and non-fluoridated populations to determine if there are differences between these populations at low levels of caries severity as well as the more established assessment of caries at a diagnostic threshold of caries into dentine. This will permit possible comparisons with data generated from the Tiel-Culemborg study in the Netherlands with respect to the progression of white spot lesions in to cavitated lesions and possible effects of water fluoridation on the prevalence and severity of caries.

The aims of this study were to determine the effect of social deprivation on the prevalence of caries (including caries lesions restricted to enamel) and enamel fluorosis (on the maxillary central incisors) in areas served by either fluoridated or non-fluoridated drinking water. The study also aimed to explore the use of remote, blinded methodologies to minimize the effect of examiner bias using clinical scoring and remote blinded photographic scoring employing ICDAS criteria for caries and fluorescence imaging for fluorosis.

Subjects and Methods

The study was conducted in two localities with and without fluoridated community water supplies, Newcastle upon Tyne (Fluoridated at 1ppm F) and Greater Manchester (non-fluoridated). Ethical approval for the study was obtained from the University of Manchester Committee on the Ethics of Research on Human Beings (ref: 07952). Permission was sought from relevant Local Authorities to approach schools in their locality. Schools were selected based upon the percentage free school meals entitlement (%FSME) to provide a spectrum of socio-economic backgrounds (Shuttleworth 1995) and their willingness to participate. Letters were sent to the parents of male and female pupils in years 7 and 8 (aged 11-13) containing information sheets for parents and pupils together with parental opt-out forms with a stamped addressed envelope to return to the study team if the parent or carer did not wish their child to participate. Two weeks before the scheduled school visit a reminder and further opportunity to opt-out was sent to each parent who had not previously returned an opt-out form.

The study ran between February 2008 and December 2009. Blocks of examination time were arranged to take into consideration school availability during term time and were balanced between the localities to minimize examination bias and to ensure the age ranges of the subjects were comparable between the localities.

Pupils whose parents had not returned an opt-out form attended for recruitment and were invited to participate in the study. Written informed consent was obtained for each subject. During the recruitment phase, lifetime residency in the locality and residential postcode were confirmed. Subjects who were not lifetime residents were withdrawn from the study. Postcode details for each participant enabled an individual level measure of social deprivation to be ascribed using the Index of Multiple Deprivation (IMD). Consented subjects were asked to complete a short pictorial computer based questionnaire on oral hygiene practices: type of brush, quantity of paste and rinsing habits.

Clinical examinations were undertaken by a single trained examiner (MGM) for caries using ICDAS criteria (Pitts 2004; Ismail, Sohn et al. 2007) under standard lighting conditions together with a portable chair, air compressor and disposable instruments for examination. Intra-oral images were taken of the teeth using a SOPRO 717 intra-oral camera (Acteon Group, USA) and a bespoke software package that enabled image capture for each tooth linking it to the subject identifier. The images were integrated into a graphical user interface that randomized and blinded the images which were then displayed on a 32 inch flat screen monitor under controlled lighting. This ensured the examiner was unaware of the area of residence of the subject and each image was scored under identical conditions. This enabled comparison with the clinical caries scores. A selection of subjects from each locality was asked to return for reproducibility scores a minimum of 30 minutes after their initial examination. This was based on logistical and time constraints and subject willingness to return to for examination.

Following the clinical examination, the maxillary central incisors were dried for 1 minute with cotton roll and standardized digital photographs taken using a Nikon D100 camera, Micro Nikkor 105 mm f2.8 lens and a Nikon SB21 ring flash (Cochran, Ketley et al. 2004). None of the images contained identifying subject features. The images were exported to a computer and linked to a photographic log using a unique subject identifier. All images were scored remotely by the examiner in a blind manner for fluorosis using Thylstrup and Fejerskov (TF) index (Thylstrup and Fejerskov 1978) on completion of the clinical phase of the study using the same methodology as the intra oral images for caries scoring. The highest TF score given to either maxillary central incisor was the value recorded for a subject. No substitutions were permitted in the event of missing or un-assessable teeth. A random selection of images was selected in order to obtain reproducibility scores.

Before completing the study visit, subjects were provided with a 3 day food diary to complete together with instructions. A random cohort of subjects across both localities were asked to return with their diaries for an in depth interview with a dietician to assess intake of non milk extrinsic sugars (NMES).

Statistical methods

Data from the caries examinations was recorded on case report forms and entered into Statistical Package for Social Sciences (SPSS 16.0) for statistical analysis. Data for the intra-oral caries images and the fluorosis scores from the photographic images were recorded directly by an interface into a Windows (Microsoft Corp., Seattle, Wash., USA) excel file and imported into SPSS for statistical analysis.

For logistical reasons and to avoid issues with re-hydration of lesions, only images of dry teeth were taken with the intra-oral camera. To facilitate comparison between clinical and photographic caries scores ICDAS codes 1 and 2 were collapsed and reported as code 2. Caries data for DMFT were calculated for each subject using the ICDAS code for the D component. Caries experience at white spot lesion (or worse) was calculated as D_{1-6}MFT (as some ICDAS code 1 lesions would be classified as ICDAS code 2). Caries experience thresholded at visible caries into dentine was calculated as D_{4-6}MFT. Surfaces with sealants were considered to be sound.

Demographical, oral hygiene practices and deprivation data were explored to determine if significant differences existed between the two localities using t-tests and Mann-Whitney-U tests.

Reproducibility measures for clinical caries scores and fluorosis scores were analyzed using the Kappa statistic. Differences between the fluoridated and non-fluoridated localities for proportions of subjects with fluorosis and caries DMFT scores were tested for statistical significance using the chi-square test.

The relative effects of independent variables for age at examination and IMD score on the presence or absence of caries and fluorosis were determined using a logistic regression model for the fluoridated and non-fluoridated localities.

Results

In total data for 1783 examined subjects were available for analysis. A flow chart of subjects is shown in Figure 8.1. Subject demographical data are detailed in Table 8.1. Overall, measures taken at recruitment to obtain balance between the two localities with respect to age at exam, gender and level of deprivation were generally successful with no significant differences between Newcastle and Manchester.

The data in Table 8.2 summarizes some of the findings from the oral hygiene practices questionnaire and the cohort of subjects that undertook the dietary interview. The cohort data suggested that between the two study areas there were no significant differences either in terms of frequency of NMES intake or NMES consumed in the last hour before bedtime. The oral hygiene practices data revealed no significant differences between the two populations with the exception of rinsing habits where 16% of subjects in Manchester reported not rinsing after brushing compared to only 9% in Newcastle (p=0.0001). In both populations approximately 40% of subjects reported rinsing with a glass or beaker.

DMFT data generated for each subject for D_{1-6}MFT and D_{4-6}MFT are illustrated in Tables 8.3 and 8.4. At both thresholds, clinical and photographic DMFT scores for Newcastle were significantly lower than for subjects residing in Manchester (p<0.0001). The mean D_{1-6}MFT in Newcastle was 2.94 (clinical); 2.51 (photo) and for Manchester 4.48 (clinical); 3.44 (photo). For visible caries into dentine the mean D_{4-6}MFT in Newcastle was 0.65 (clinical); 0.58 (photo) and for Manchester the mean D_{4-6}MFT was 1.07 (clinical); 0.98 (photo). This is illustrated in Table 8.3.

The percentage of children caries free differed between the two cities for both thresholds of caries detection. In Newcastle 25% were caries free at white spot lesion threshold and 67% for caries into dentine. In Manchester these figures were lower with 15% and 54% respectively for clinical scores ($p<0.0001$). Summary data from the NHS DEP 12 year survey for each locality is also shown in Table 8.3 for illustrative purposes. The NHS DEP survey was carried out in the same populations whilst this study was ongoing, although caution should be taken when drawing conclusions from comparisons between the datasets. The components of DMFT for each detection threshold are illustrated in Figure 8.2 demonstrating the differences between the fluoridated and non-fluoridated populations.

The descriptive data was explored to identify differences between the two localities. Table 8.4 outlines the frequency distributions between the study groups for DMFT counts for both clinical and photographic scores. The data suggests when detection criteria are set at the level of caries into dentine there are clear differences between the fluoridated and non-fluoridated populations ($p<0.0001$). However, if the detection threshold is changed to white spot lesion level these differences are reduced but still significant ($p<0.0001$). The data sets were comparable between the two scoring techniques, particularly at a threshold of caries into dentine with both techniques (clinical and photographic scoring) demonstrating significant differences between fluoridated Newcastle and non-fluoridated Manchester ($p<0.0001$). Data from repeat examinations were available for 47 subjects. Weighted Kappa statistics for comparison of ICDAS tooth surface scores were generated and showed excellent agreement (weighted Kappa = 0.80) (Landis and Koch 1977).

Comparisons were made between the DMFT scores derived from clinical ICDAS scores and those generated from remote blind scoring of the intra-oral photographs (Tables 8.3 and 8.4). Unexpectedly, the photographic DMFT scores were consistently lower than the clinical scores. However, the differences between the two localities were consistent and it was inferred there was minimal effect of bias in the clinical scoring. The data also suggested there appears to be no loss of discrimination using the remote photographic scoring technique.

To explore possible explanations for the lower scores from the photographs crosstab data for ICDAS scores was analyzed between the clinical and photographic techniques. An example is demonstrated in Table 8.5 illustrating the comparison between scoring techniques for the occlusal surface of the upper right first molar. It is clear from the data in Table 8.5 there are some differences in scores between the two techniques particularly where a code 2 has been called clinically and the surface called 0 from the photograph (n=252). Whilst misclassifications are always a possibility i.e. a fissure sealant called as a restoration or vice versa, the data would suggest there may be issues with either examiner thresholding or confounding issues with the intra-oral images particularly at low caries severity.

The association between quintiles of deprivation and mean DMFT is shown in Table 8.6, with 1 being the least deprived and 5 being the most deprived. The data demonstrates for both thresholds there was an increase in mean DMFT with increasing deprivation for both the fluoridated and non-fluoridated populations. However, the social gradient between caries and deprivation appeared to be lower in Newcastle when compared to Manchester. This is illustrated in Figure 8.3. There were significant differences between Newcastle and Manchester across each quintile of deprivation for both white spot lesion threshold and caries into dentine ($p<0.001$). The only exception to this was the least deprived quintile, where caries in Newcastle was lower compared to Manchester, but this was not statistically significant for either detection threshold.

Data was generated for the proportion of subjects who were “caries free” in each quintile of deprivation. This was performed for both detection thresholds (white spot lesion and caries into dentine) and both detection methods (clinical and remote photographic scoring). This is illustrated in Table 8.7. The data demonstrated for each quintile of deprivation and for both detection methods and thresholds there were greater numbers of “caries free” subjects in fluoridated Newcastle compared to non-fluoridated Manchester. Line graphs of this data (Figure 8.4) demonstrate the differences between the fluoridated and non-fluoridated populations. The difference in gradient between the lines appears to be greater when considering caries into dentine for both clinical and photographic scoring. It would appear in the fluoridated population in Newcastle there is a reduction in the social gradient between caries and deprivation for caries into dentine. When considering caries at white spot lesion, the difference in gradient is less pronounced but the proportion "caries free" remains consistently higher in Newcastle.

The prevalence and severity of fluorosis on the maxillary central incisors in Newcastle and Manchester was obtained from the blinded scoring of photographs, the results are described in Table 8.8. In total there were 1775 subjects with satisfactory photographic information (906 Newcastle; 869 Manchester). The prevalence of fluorosis in fluoridated Newcastle was 55%, in non-fluoridated Manchester it was 27%. In Newcastle, 48% of subjects had TF scores of 1 or 2 and 7.1% of subjects had TF scores of 3 or greater. In Manchester the corresponding values were 26% and 1.2% respectively. Data from repeat scoring of photographic images were available for 98 subjects. Very good agreement was found between the initial scoring and repeats (weighted Kappa =0.75) (Landis and Koch 1977).

Initial comparisons of the data between Newcastle and Manchester for caries and fluorosis were carried out using chi-square tests to generate Odds Ratios (Table 8.9). When considering the presence or absence of caries at a threshold of white spot lesion, subjects in Manchester were 1.9 times more likely to have caries than subjects in Newcastle ($p<0.001$). At a threshold of visible caries into dentine, subjects in Manchester were 1.8 times more likely to have caries than subjects in Newcastle ($p<0.001$). Subjects in Newcastle were 3.3 times more likely to have fluorosis than subjects in Manchester ($p<0.001$). when the severity of fluorosis was thresholded at TF 3 or higher this rose to 10.5 times more likely in Newcastle compared to Manchester ($p<0.001$).

The effect of age at exam and deprivation on the outcomes of caries and fluorosis were explored using logistic regression models. As a result of the potential loss of information from the photographic scores for caries the analysis comparing the two localities was carried out using the clinical ICDAS caries scores. This is demonstrated in Table 8.10. The logistic regression models produced similar Odds Ratios to the raw Odds Ratios in Table 8.9. The explanatory variables of city (fluoridation status), age at exam and quintile of IMD were entered into a logistic regression model with the presence or absence of caries into dentine as the outcome variable. All three variables were statistically significant. The Odds

Ratio for developing caries of 1.840 (95% CI 1.500, 2.258) for children in Manchester compared to Newcastle (assuming other explanatory variables held constant). The model also demonstrated increasing Odds Ratios for caries with each increase in quintile of deprivation and an Odds Ratio of 1.347 (95% CI 1.123, 1.616) for developing caries in to dentine with each additional year of life. The model was shown to have very good predictive value. The positive predictive value is defined as the proportion of subjects with positive results who are correctly identified and is critically dependent on the prevalence of the condition under investigation.

The model created for caries at a white spot lesion threshold provided an Odds ratio of 2.11 (95% CI 1.622, 2.680) for children in Manchester compared to Newcastle. Once again, Odds Ratios increased as quintile of deprivation increased as did the Odds Ratio for age at exam. However, the predictive value for this model was lower than the model for caries into dentine.

Explanatory variables for city (fluoridation status) and quintile of IMD were entered into a logistic regression model with the presence or absence of fluorosis as the dependent variable. The Odds Ratio for developing fluorosis was 3.390 (95% CI 2.780, 4.152) times greater in Newcastle when compared to Manchester. The effect of deprivation on fluorosis was only significant for subjects in the least deprived quintile of IMD. The Odds Ratio of developing fluorosis was 1.508 (95% CI 1.101, 2.065) for those in the least deprived quintile of IMD when compared to the most deprived quintile. This model had a reasonable predictive value.

A logistic regression model looking at the presence or absence of fluorosis at a severity of TF Index of 3 or higher produced an Odds Ratio of 10.424 for Newcastle compared to Manchester. However, whilst this was significant, the model was deemed to be unstable because of the low numbers of cases in at least one of the cells. Caution should be taken when interpreting the results from this model.

Discussion

This study supports the existing evidence from other studies conducted in the UK that water fluoridation can reduce inequalities in health by reducing the social gradient between deprivation and dental caries (Carmichael, French et al. 1984; Ellwood and O'Mullane 1995; Jones and Worthington 1999; Riley, Lennon et al. 1999; Jones and Worthington 2000). Using IMD as a measure of deprivation enabled a more accurate assessment of deprivation for individuals by allocation of a score for at a LSOA level via postcode rather than at the electoral ward level. This avoided analysis of the data by mean DMFT scores at a ward level. By initially selecting schools through %FSME, it facilitated a more balanced profile of deprivation albeit resulting in selected populations. However, this study demonstrated the risks and benefits associated with the use of fluorides in dentistry remain an important consideration.

Despite the significant difference in caries prevalence and severity in Newcastle compared to Manchester, it has been achieved with an increased prevalence in fluorosis. The overall prevalence of fluorosis in Newcastle is comparable to that observed by Tabari and Ellwood et al (Tabari, Ellwood et al. 2000) in a study conducted in Newcastle and non-fluoridated Northumberland but the prevalence of fluorosis at a severity of TF 3 or greater appears to have increased from 3.4% to 7% in the ten years separating the two studies. Caution should be taken when interpreting these results. Whist both studies adopted the same index and method of remote scoring of standardized photographs, the primary analysis of the earlier study employed the use of clinical scores that could potentially result in changes in detection thresholds. Furthermore, without the re-scoring of the images from the first study by the examiner of the current study it is not possible to ascertain if personal thresholding or the effect of image magnification in the current study has affected the outcome (Tavener, Davies et al. 2007). As the numbers of subjects in the more severe categories are relatively low, small changes in the number of subjects in these cells can dramatically affect Odds Ratios.

It is important to remember this study has only reported fluorosis prevalence and severity on the maxillary central incisors. This is largely owing to the fact these teeth are the most practical from which to obtain good images and are considered important in assessing aesthetics. The risk period for fluorosis for these teeth is open to debate, but it is generally accepted they are generally at greatest risk from birth up to the age of three years (Evans and Darvell 1995; Hong, Levy et al. 2006; Hong, Levy et al. 2006). In essence this study is examining the effects of fluoride exposure in infancy. However, risk assessments for fluorosis should not be confined to the maxillary central incisors but to the whole dentition taking into account the overall exposure to fluoride in terms of dose and length of duration of exposure (Hong, Levy et al. 2006). It was not practical to assess fluorosis on the remaining dentition therefore it is not possible to draw conclusions on any differences in fluorosis prevalence and severity outside of the parameters defined in this study. Differences in feeding practices, growth and development and oral hygiene practices may have an effect on fluorosis presentation on teeth erupting after the maxillary central incisors. It is entirely plausible the apparent increase in fluorosis prevalence at higher severities in Newcastle is as a result of excessive fluoride derived from an additive effect of water fluoridation and potential misuse of fluoridated dental products. This is not a novel concept (Rock and Sabieha 1997; Whelton, Ketley et al. 2004) and has been addressed in some areas with fluoridated water supplies. The Republic of Ireland has recently amended the content of fluoride in water supplies in 2007 from 1ppmF to 0.7ppmF following a review (2002) and in the United States the U.S. Health and Human Services together with the Environmental Protection Agency has recommended a similar reduction in water fluoride content following a report from the National Academies of Science (2006). This will require evaluation to monitor not only changes in fluorosis prevalence but also any detrimental effects on caries prevalence particularly in more deprived communities.

This study supports the existing evidence suggesting the use of water fluoridation and fluoridated dentifrice has a greater impact on caries levels than the use of fluoridated dentifrice alone. Studies in the permanent dentition have provided variable results and it was suggested by Ellwood and O’Mullane (Ellwood and O'Mullane 1995) that it is more difficult to demonstrate differences when population caries levels are low. When examining the confidence intervals for mean DMFT for Newcastle and Manchester at both thresholds of detection there is no overlap suggesting significant differences exist in caries levels. The use of ICDAS criteria in calculating DMFT permits analysis of early carious lesions as well as the more traditional visible caries into dentine employed by the NHS DEP. This is a potentially useful epidemiological tool as it could facilitate the longitudinal monitoring of early carious lesions and explore the behaviour of such lesions in an individual over time. Examination of the results of this study reveal the difference in prevalence between the fluoridated population and the non-fluoridated are reduced when the caries is reported at a threshold of white spot lesions. The question is raised whether water fluoridation prevents or merely delays the progression of early caries. This could only be answered by longitudinal examination but the findings of this study are consistent with those conducted in the Netherlands in Tiel and Culemborg although it should be stressed there was no assessment of lesion activity undertaken in this study.

The logistic regression models for caries demonstrated good levels of prediction when considering fluoridation status, deprivation and age at examination as explanatory variables. However, the effect size was relatively low suggesting other factors influenced caries risk to a greater extent. It is obvious both diet and oral hygiene practices will have a great effect on caries risk for an individual and are important considerations to include in the development of caries risk models to improve on current models lacking reliable means of accurately predicting caries risk (Milsom and Tickle 2010). Nevertheless it has been demonstrated that deprivation and fluoridation status will have an effect on caries risk and are important considerations to make when evaluating both passive population based preventative interventions such as water fluoridation and targeted interventions such as topical fluoride applications for high caries risk individuals.

There were several logistical difficulties encountered during this study. All of the subjects were examined during academic term time in a school setting which created several logistic difficulties during both the planning and execution phases. Secondary schools have a congested curriculum and required the permission not only of the local authorities but of the head teachers of each school to facilitate time and space to minimize disruption to the academic timetable but also physical space in which to perform the examinations. Whilst this was generally successful in enabling examinations there were a number of instances where conflicts in school timetables could not permit additional visits to examine absentees or pupils with alternate commitments. This was reflected in Manchester where there were a disproportionate number of subjects unavailable owing to proximity to the Christmas holidays and related events organized in school (Figure 8.1).

Additional difficulties and limitations should be considered in a study of this nature. Following the recommendations from the York Report (NHS-CRD 2000) it is accepted that a cross sectional study is not the most robust design for assessing the impact of water fluoridation. However, the cost implications for a study design that would include prospective monitoring of birth cohorts, serial cross sectional surveys that include analysis of diet and total fluoride intake with anthropometric measurements would be cost prohibitive and beyond the remit of this project. Nevertheless, the aforementioned are important considerations to be taken during study design.

This study did include an assessment of dietary intake of sugars through an interview process with a dietician on a representative cohort, but this was not a practical consideration for the entire study population and acted merely to demonstrate there were no significant differences between the populations with respect to caries risk from dietary intake of NMES. The oral hygiene practices questionnaire was unable to assess previous fluoride intake and any interview recall of infant practices would be prone to bias. Assumptions were made that most subjects (if not all) used fluoridated dentifrice and they were questioned on use of fluoride supplements which only elicited a positive response by very few subjects (Figure 8.1). The results are interesting to report whereby significantly more subjects in Manchester reported not rinsing after brushing which would assist in the maintenance of the oral fluoride reservoir. However, it is important to note when considering the study population as a whole an overwhelming proportion are not following the current recommendations of expectorating but not rinsing after brushing (2009). During the study design phase the option of including anthropometric measurements was discussed but as it would have generated little additional value in context with other captured data and potentially impacted upon consent rates, it was decided not to pursue this option.

The consent rate is an important consideration to make in a study of this nature with respect to the validity of the data and the representative value of the study population. The consent rate when considering all subjects available for examination was 63.1% (64.3% Newcastle; 61.7% Manchester). These figures are low when considering the level of consent rates expected for observational surveys, but in the absence of a negative consent process the consent rates in this study are commensurate with those of a survey using a positive consent process such as the NHS DEP. The demographics and caries status of the subjects who did not participate remain unknown as is the impact their data would have on study outcomes. There is the possibility this would have the effect of underestimating the effect of deprivation and caries as it would be reasonable to assume subjects that did not consent or attend for examination had high caries levels.

The populations examined in this study should be correctly described as being selected populations. Whilst most of the state secondary schools in Newcastle participated in the study there were three state schools who did not participate as well as public and private school who were not approached. In order to minimize bias between the populations the schools approached in Manchester were targeted to enable an equitable balance in deprivation between the fluoridated and non-fluoridated populations. Therefore many of the inner city schools in Manchester were not approached owing to high non-lifetime residency of pupils or the %FSME profile did not match an equivalent school in Newcastle.

The results from the use of the intra-oral camera for remote scoring demonstrated a potential means of blinded assessment. It had been hypothesised that the use of the camera would reduce the level of potential examiner bias and the images would be able to facilitate longitudinal assessment through the use of video repositioning (VidRep) software. The DMFT for the photographs were consistently lower than the clinical scores and it was felt that the lack of clear visualization of the interproximal surfaces together with confounding from specula reflection may have impacted on the results. However, the technique demonstrated the ability to discriminate between the populations and comparison of the ICDAS scores for the occlusal surfaces of the first molars between the photograph and clinical scores produced a weighted Kappa statistic of 0.83 suggesting a very good level of agreement between the methodologies when comparing the same high caries risk surface (Landis and Koch 1977). The similarities between the clinical and photographic scoring methods are encouraging despite the acknowledged confounding issues. Additional work is required to improve intra-oral image capture and investigate the reasons for the differences in severity scores but the incorporation of a polarizing filter may reduce the effect of specula reflection on subsequent image scoring. The difficulties associated with the visualization of the interproximal surfaces may be more problematic to address.

The comparison between the results of this study and those of the NHS DEP that were carried out in largely the same population are interesting but do require caution and qualification. The remit of this study was to utilize the ICDAS criteria in order to detect early caries rather than at the D_3 level used in the BASCD criteria employed in the NHS DEP survey. Comparisons between indices and the pragmatic use of ICDAS with single representative scores on surfaces have been reported in the literature with favourable outcomes (Mendes, Braga et al.; Braga, Oliveira et al. 2009; Jablonski-Momeni, Ricketts et al. 2009). The comparisons between the datasets for caries into dentine (ICDAS code 4 and D_3) and also for lifetime versus non lifetime residents in Newcastle are interesting and would require a more thorough investigation to validate but the inference from the data is there is a possible effect on caries for lifetime residents in the fluoridated population examined in this study compared to the population examined in the NHS DEP.

Conclusions

The results of this study support existing work suggesting water fluoridation together with the use of fluoridated dentifrice provides improved caries prevention over the use of fluoridated dentifrice alone. The social gradient between caries and deprivation appears to be lower in the fluoridated population compared to the non-fluoridated population, particularly when considering caries into dentine, demonstrating a reduction in inequalities of oral health for the most deprived individuals in the population. However, the risk of developing fluorosis is increased in the fluoridated population when associated with the widespread use of fluoridated dentifrice, particularly in the least deprived individuals. The use of ICDAS may provide greater flexibility to report and monitor early carious lesions more favourably than existing methods employed in oral health surveys. The use of intra-oral cameras for blinded caries scoring demonstrated the ability to discriminate between a fluoridated and non-fluoridated population and has good potential for blinded caries assessment but the technique requires additional work to address potential information loss and confounding issues.

Acknowledgements

The authors wish to thank the pupils and staff at the schools who participated, Dianne Tabari, Deborah Howe and Valerie Dalton from Newcastle Primary Care Trust for their support and assistance during this project. Dr Pretty is funded by a Clinician Scientist Award from the National Institute for Health Research (UK). This research was supported by Colgate Palmolive Dental Health Unit, Manchester, UK.

References

(2002). Forum on Fluoridation. Dublin, Stationary Office.

(2006). Fluoride in Drinking Water. A Scientific Review of EPA's Standards. Washington DC, The National Acadamies Press, National Research Council.

(2009). Delivering Better Oral Health: An evidence-based toolkit for prevention. Gateway Ref: 122231. 2009., Department of Health and the British Society for the Study of Community Dentistry.

Backer Dirks, O., B. Houwink, et al. (1961). "The results of 6 1/2 years of artificial fluoridation of drinking water in the Netherlands. The Tiel-Culemborg experiment." Arch Oral Biol **5**: 284-300.

Braga, M. M., L. B. Oliveira, et al. (2009). "Feasibility of the International Caries Detection and Assessment System (ICDAS-II) in epidemiological surveys and comparability with standard World Health Organization criteria." Caries Res **43**(4): 245-9.

Carmichael, C. L., A. D. French, et al. (1984). "The relationship between social class and caries experience in five-year-old children in Newcastle and Northumberland after twelve years' fluoridation." Community Dent Health **1**(1): 47-54.

Carmichael, C. L., A. J. Rugg-Gunn, et al. (1989). "The relationship between fluoridation, social class and caries experience in 5-year-old children in Newcastle and Northumberland in 1987." Br Dent J **167**(2): 57-61.

Carmichael, C. L., A. J. Rugg-Gunn, et al. (1980). "The effect of fluoridation upon the relationship between caries experience and social class in 5-year-old children in Newcastle and Northumberland." Br Dent J **149**(6): 163-7.

Cochran, J. A., C. E. Ketley, et al. (2004). "A standardized photographic method for evaluating enamel opacities including fluorosis." Community Dent Oral Epidemiol **32 Suppl 1**: 19-27.

Dean, H. T. (1938). "Endemic Fluorosis and its relation to dental caries." Public Health report **53**: 1443-1452.

Dean, H. T., F. A. Arnold, et al. (1942). "Domestic water and dental caries. V. Additional studies of the relation of fluoride domestic waters to dental caries experience in 4,425 white children aged 12-14 years of 13 cities in 4 states." Public Health Rep **57**: 1155-79.

Dean, H. T., F. A. Arnold, et al. (1950). "Studies on mass control of dental caries through fluoridation of the public water supply." Public Health Rep **65**: 1403-8.

DHSS (1980). Inequalities in Health: Report of a Working Group Chaired by Sir Douglas Black. . London, DHSS.

Ellwood, R. P., G. M. Davies, et al. (2004). "Relationship between area deprivation and the anticaries benefit of an oral health programme providing free fluoride toothpaste to young children." Community Dent Oral Epidemiol **32**(3): 159-65.

Ellwood, R. P. and D. M. O'Mullane (1994). "The demographic and social variation in the prevalence of dental enamel opacities in north Wales." Community Dent Health **11**(4): 192-6.

Ellwood, R. P. and D. M. O'Mullane (1995). "The association between area deprivation and dental caries in groups with and without fluoride in their drinking water." Community Dent Health **12**(1): 18-22.

Evans, R. W. and B. W. Darvell (1995). "Refining the estimate of the critical period for susceptibility to enamel fluorosis in human maxillary central incisors." J Public Health Dent **55**(4): 238-49.

French, A. D., C. L. Carmichael, et al. (1984). "Fluoridation and dental caries experience in 5-year-old children in Newcastle and Northumberland in 1981." Br Dent J **156**(2): 54-7.

Groeneveld, A. (1985). "Longitudinal study of prevalence of enamel lesions in a fluoridated and non-fluoridated area." Community Dent Oral Epidemiol **13**(3): 159-63.

Groeneveld, A., A. A. Van Eck, et al. (1990). "Fluoride in caries prevention: is the effect pre- or post-eruptive?" J Dent Res **69 Spec No**: 751-5; discussion 820-3.

HMSO (1962). Ministry of Health, Scottish Office & Ministry of Housing and Local Government (1962) The Conduct of the Fluoridation Studies and the Results Achieved after Five Years. (Reports on Public Health and Medical Subjects No.105). London, HMSO.

HMSO (1969). Department of Health and Social Security, Scottish Office,Welsh Office & Ministry of Housing and Local Government (1969) The Fluoridation Studies in the United Kingdom and the Results Achieved after Eleven Years (Reports on Public Health and Medical Subjects No.122) London, HMSO.

Hong, L., S. M. Levy, et al. (2006). "Timing of fluoride intake in relation to development of fluorosis on maxillary central incisors." Community Dent Oral Epidemiol **34**(4): 299-309.

Hong, L., S. M. Levy, et al. (2006). "Fluoride intake levels in relation to fluorosis development in permanent maxillary central incisors and first molars." Caries Res **40**(6): 494-500.

Horowitz, H. S. (1996). "The effectiveness of community water fluoridation in the United States." J Public Health Dent **56**(5 Spec No): 253-8.

Hulse, G., A. Kenrick, et al. (1995). "Welsh water should reinstate fluoridation on Anglesey." Br Dent J **178**(2): 46-7.

Ismail, A. I., W. Sohn, et al. (2007). "The International Caries Detection and Assessment System (ICDAS): an integrated system for measuring dental caries." Community Dent Oral Epidemiol **35**(3): 170-8.

Jablonski-Momeni, A., D. N. Ricketts, et al. (2009). "Impact of Scoring Single or Multiple Occlusal Lesions on Estimates of Diagnostic Accuracy of the Visual ICDAS-II System." Int J Dent **2009**: 798283.

Jackson, D., P. M. James, et al. (1985). "Fluoridation in Anglesey 1983: a clinical study of dental caries." Br Dent J **158**(2): 45-9.

Jackson, D., P. M. James, et al. (1975). "Fluoridation in Anglesey. A clinical study." Br Dent J **138**(5): 165-71.

Jarman, B. (1983). "Identification of underprivileged areas." Br Med J (Clin Res Ed) **286**(6379): 1705-9.

Jones, C. M. and H. Worthington (1999). "The relationship between water fluoridation and socioeconomic deprivation on tooth decay in 5-year-old children." Br Dent J **186**(8): 397-400.

Jones, C. M. and H. Worthington (2000). "Water fluoridation, poverty and tooth decay in 12-year-old children." J Dent **28**(6): 389-93.

Kwant GW, Houwink B, et al. (1973). "Artificial fluoridation of drinking water in the Netherlands. Results of the Tiel-Culembourg experiment after 161/2 years." Neth Dent J **80**: 6-27.

Landis, J. R. and G. G. Koch (1977). "An application of hierarchical kappa-type statistics in the assessment of majority agreement among multiple observers." Biometrics **33**(2): 363-74.

Macintyre, S. (1997). "The Black Report and beyond: what are the issues?" Soc Sci Med **44**(6): 723-45.

Maguire, A., F. V. Zohouri, et al. (2007). "Fluoride intake and urinary excretion in 6- to 7-year-old children living in optimally, sub-optimally and non-fluoridated areas." Community Dent Oral Epidemiol **35**(6): 479-88.

Mendes, F. M., M. M. Braga, et al. "Discriminant validity of the International Caries Detection and Assessment System (ICDAS) and comparability with World Health Organization criteria in a cross-sectional study." Community Dent Oral Epidemiol **38**(5): 398-407.

Milsom, K. M. and M. Tickle (2010). "Preventing decay in children: dare we risk the 'risk assessment' model in practice?" Br Dent J **209**(4): 159-60.

MRC (2002). Medical Research Council Working Group Report. Water fluoridation and health. London, MRC.

Murray, J. J., P. H. Gordon, et al. (1984). "Dental caries and enamel opacities in 10-year-old children in Newcastle and Northumberland." Br Dent J **156**(7): 255-8.

NHS-CRD (2000). A Systematic Review of Public Water Fluoridation. York, The University of York, NHS Centre for Reviews and Dissemination (Report 18).

Noble, M., D. McLennan, et al. (2008). The English Indices of Deprivation 2007. London, Social Disadvantage Research Centre, University of Oxford.

Pitts, N. (2004). ""ICDAS"--an international system for caries detection and assessment being developed to facilitate caries epidemiology, research and appropriate clinical management." Community Dent Health **21**(3): 193-8.

Pitts, N. B. (2001). "Clinical diagnosis of dental caries: a European perspective." J Dent Educ **65**(10): 972-8.

Pitts, N. B. (2004). "Modern concepts of caries measurement." J Dent Res **83 Spec No C**: C43-7.

Pitts, N. B., D. J. Evans, et al. (1997). "British Association for the Study of Community Dentistry (BASCD) diagnostic criteria for caries prevalence surveys-1996/97." Community Dent Health **14 Suppl 1**: 6-9.

Pretty, I. A. (2006). "Caries detection and diagnosis: novel technologies." J Dent **34**(10): 727-39.

Riley, J. C., M. A. Lennon, et al. (1999). "The effect of water fluoridation and social inequalities on dental caries in 5-year-old children." Int J Epidemiol **28**(2): 300-5.

Rock, W. P. and A. M. Sabieha (1997). "The relationship between reported toothpaste usage in infancy and fluorosis of permanent incisors." Br Dent J **183**(5): 165-70.

Rugg-Gunn AJ, Carmichael CL, et al. (1977). "Fluoridation in Newcastle and Northumberland: a clinical study of 5-year-old children. ." British Dental Journal **142**: 359-402.

Rugg-Gunn, A. J., C. L. Carmichael, et al. (1988). "Effect of fluoridation and secular trend in caries in 5-year-old children living in Newcastle and Northumberland." Br Dent J **165**(10): 359-64.

Shuttleworth, I. (1995). "The Relationship between Social Deprivation, as Measured by Individual Free School Meal Eligibility, and Educational Attainment at GCSE in Northern Ireland: A Preliminary Investigation." British Educational Research Journal **21**(4): 487-504.

Tabari, E. D., R. Ellwood, et al. (2000). "Dental fluorosis in permanent incisor teeth in relation to water fluoridation, social deprivation and toothpaste use in infancy." Br Dent J **189**(4): 216-20.

Tavener, J., R. M. Davies, et al. (2007). "Agreement amongst examiners assessing dental fluorosis from digital photographs using the TF index." Community Dent Health **24**(1): 21-5.

Thylstrup, A. and O. Fejerskov (1978). "Clinical appearance of dental fluorosis in permanent teeth in relation to histologic changes." Community Dent Oral Epidemiol **6**(6): 315-28.

Townsend, P., P. Phillimore, et al. (1988). Health and deprivation: inequality and the North. London, Croom Helm.

Watt, R. and A. Sheiham (1999). "Inequalities in oral health: a review of the evidence and recommendations for action." Br Dent J **187**(1): 6-12.

Whelton, H., E. Crowley, et al. (2004). "Dental caries and enamel fluorosis among the fluoridated and non-fluoridated populations in the Republic of Ireland in 2002." Community Dent Health **21**(1): 37-44.

Whelton, H. P., C. E. Ketley, et al. (2004). "A review of fluorosis in the European Union: prevalence, risk factors and aesthetic issues." Community Dentistry and Oral Epidemiology **32**(s1): 9-18.

Zohouri, F. V., A. Maguire, et al. (2006). "Sources of dietary fluoride intake in 6-7-year-old English children receiving optimally, sub-optimally, and non-fluoridated water." J Public Health Dent **66**(4): 227-34.

Table 8.1. Subject demographics

City	Subject Numbers	Mean age at exam (SD)	Gender %		Mean IMD (range)
			M	F	
Newcastle	910	12.56 (0.48)	54	46	35.22 (2.77-78.85)
Manchester	873	12.32 (0.64)	57	43	37.04 (1.84-84.02)
Total	1783	12.44 (0.57)	56	44	36.11 (1.84-84.02)

Table 8.2. Summary data for dietary interviews on sugar consumption and oral hygiene practices.

	Manchester (N=63)	Newcastle (N=65)	Significance
Diet data - Mean			
			Mann Whitney U
NME Sugar between meals	1.95	1.86	U = 1989.5, z = -0.284, p= 0.776
NME Sugar last hour before bed	0.48	0.45	U = 2019, z = -0.159, p= 0.874
Brushing data- Percentiles			
	Manchester (N=873)	Newcastle (N=891*)	
Toothpaste			
small pea	10%	3%	U =369047, z =-1.954, p = 0.051
thin smear	34%	40%	
large pea	28%	27%	
full brush head	28%	30%	
Rinse behaviour –			*Chi square*
No Rinsing	16%	9%	x(2) = 15.9, p=0.0001**
Wet brush	12%	14%	p=0.203
Head under tap	19%	18%	p=0.839
Cupped hands	14%	17%	p=0.039
Glass or beaker	41%	42%	p=0.644

*19 subjects had incomplete data and were excluded from examination
**Significant result

Table 8.3. Table 8.3. Descriptive DMFT data for both cities, at white spot lesion and caries into dentine. Data from NHS DEP survey 2008 on 12 year olds shown for both cities.

	Mean $D_{1-6}MFT$ white spot (SD)	95% confidence Interval		Mean $D_{4-6}MFT$ dentine caries (SD)	95% confidence Interval		% $D_{1-6}MFT$ >0 white spot	% $D_{4-6}MFT$ >0 dentine caries	Mean $D_{1-6}MFT$ >0 white spot (SD)	Mean $D_{4-6}MFT$ >0 dentine caries (SD)
		Lower	Upper		Lower	Upper				
Manchester (Clinical)	4.48 (3.80)	4.23	4.73	1.07 (1.53)	0.97	1.17	85%	46%	5.29 (3.57)	2.33 (1.47)
Newcastle (Clinical)	2.94 (2.85)	2.76	3.13	0.65 (1.18)	0.58	0.73	75%	32%	3.93 (2.65)	2.01 (1.24)
Manchester (Photo)	3.44 (3.31)	3.22	3.66	0.98 (1.42)	0.88	1.07	80%	46%	4.32 (3.16)	2.15 (1.38)
Newcastle (Photo)	2.51 (2.83)	2.33	2.70	0.58 (1.09)	0.51	0.65	67%	31%	3.74 (2.71)	1.87 (1.19)
2008 12 yr old NHS DEP survey				Mean D_3MFT	95% confidence Interval			% D_3MFT>0		Mean D_3MFT>0
					Lower	Upper				
Manchester NHS DEP data				1.12	0.96	1.28		47%		2.36
Newcastle NHS DEP data				0.82	0.72	0.91		38%		2.14

Table 8.4. Frequency counts for subject DMFT status and comparison between cities for both clinical and photographic scores

	City			
	Clinical		Photo	
	Newcastle Fluoridated (910)	Manchester Non-fluoridated (873)	Newcastle Fluoridated (910)	Manchester Non-fluoridated (873)
Caries D_{1-6}MFT (white spot lesion)				
0	228 (25%)	133 (15%)	298 (33%)	177 (20%)
1	115 (13%)	78 (9%)	136 (15%)	134 (15%)
2	115 (13%)	92 (10%)	120 (13%)	112 (13%)
3	88 (10%)	103 (12%)	87 (10%)	95 (11%)
4	169 (19%)	132 (15%)	90 (10%)	91 (10%)
5	67 (7%)	53 (6%)	49 (5%)	63 (7%)
6+	128 (14%)	283 (32%)	130 (14%)	201 (23%)
	Mann Whitney U U = 303698, z =-8.683, p<0.0001		**Mann Whitney U** U = 326578, z =-6.950, p<0.0001	
	City			
	Clinical		Photo	
	Newcastle = Fluoridated (910)	Manchester = Non-fluoridated (873)	Newcastle = Fluoridated (910)	Manchester = Non-fluoridated (873)
Caries D_{4-6}MFT (caries into dentine)				
0	614 (68%)	473 (54%)	626 (69%)	475 (54%)
1	134 (15%)	149 (17%)	144 (16%)	165 (19%)
2	86 (10%)	111 (13%)	77 (9%)	112 (13%)
3	37 (4%)	58 (7%)	36 (4%)	59 (7%)
4	25 (3%)	52 (6%)	18 (2%)	44 (5%)
5	10 (1%)	18 (2%)	6 (1%)	8 (1%)
6+	3 (0.4%)	4 (1%)	3 (0.3%)	10 (1%)
	Mann Whitney U U = 337110, z =-6.300, p<0.0001		**Mann Whitney U** U = 333436, z =-6.741, p<0.0001	

Table 8.5. Crosstab data for photographic and clinical ICDAS scores for the upper right first molar (occlusal surface)

		Photographic ICDAS Score UR6 Occlusal							
		0	**2**	**3**	**4**	**5**	**6**	**F**	**S**
Clinical ICDAS Score UR6 Occlusal	**0**	506	8	0	0	0	0	2	5
	2	252	327	26	4	2	0	7	7
	3	2	66	48	3	1	0	1	1
	4	2	25	15	25	4	0	1	1
	5	0	1	5	1	7	0	2	1
	6	0	0	0	0	0	7	0	0
	F	10	3	0	0	0	0	138	4
	S	4	1	2	0	0	0	12	187

Table 8.6. Descriptive data for caries and each quintile of deprivation for white spot lesion and caries into dentine.

Quintile of deprivation	Clinical Scores				Photographic Scores			
	Newcastle		Manchester		Newcastle		Manchester	
	N	Mean $D_{1\text{-}6}MFT$ white spot lesion (SD)	N	Mean $D_{1\text{-}6}MFT$ white spot lesion (SD)	N	Mean $D_{1\text{-}6}MFT$ white spot lesion (SD)	N	Mean $D_{1\text{-}6}MFT$ white spot lesion (SD)
1	183	1.89 (2.38)	173	2.54 (2.87)	183	1.50 (2.27)	173	1.72 (2.21)
2	197	2.34 (2.41)	160	3.56 (3.16)	197	1.85(2.36)	160	2.71 (2.79)
3	213	3.25 (3.00)	148	4.41 (3.51)	213	2.67 (2.78)	148	3.37 (2.99)
4	127	3.61 (2.84)	226	5.73 (3.98)	127	3.36 (3.13)	226	4.38 (3.55)
5	190	3.80 (3.09)	166	5.76 (4.11)	190	3.45 (3.12)	166	4.72 (3.71)

Quintile of deprivation	Clinical Scores				Photographic Scores			
	Newcastle		Manchester		Newcastle		Manchester	
	N	Mean $D_{4\text{-}6}MFT$ caries into dentine (SD)	N	Mean $D_{4\text{-}6}MFT$ caries into dentine (SD)	N	Mean $D_{4\text{-}6}MFT$ caries into dentine (SD)	N	Mean $D_{4\text{-}6}MFT$ caries into dentine (SD)
1	183	0.38 (0.86)	173	0.45 (0.88)	183	0.36 (0.74)	173	0.39 (0.83)
2	197	0.47 (1.02)	160	0.84 (1.23)	197	0.38 (0.87)	160	0.77 (1.14)
3	213	0.62 (1.11)	148	1.07 (1.52)	213	0.57 (1.03)	148	1.01 (1.40)
4	127	0.87 (1.40)	226	1.37 (1.73)	127	0.79 (1.43)	226	1.24 (1.61)
5	190	0.99 (1.40)	166	1.52 (1.79)	190	0.90 (1.28)	166	1.36 (1.42)

Table 8.7. Proportion of subjects "caries free" in each quintile of deprivation for each detection method and threshold

		Proportion "Caries free" for each Quintile of Deprivation				
		1	**2**	**3**	**4**	**5**
White spot lesion Clinical	**Newcastle**	39%	32%	22%	13%	16%
	Manchester	31%	19%	12%	7%	9%
Caries in dentine Clinical	**Newcastle**	78%	75%	68%	58%	56%
	Manchester	72%	59%	57%	46%	39%
White spot lesion Photo	**Newcastle**	52%	40%	31%	17%	19%
	Manchester	37%	24%	20%	12%	10%
Caries in dentine Photo	**Newcastle**	77%	78%	69%	61%	57%
	Manchester	75%	59%	51%	48%	40%

Table 8.8. Descriptive data for fluorosis TF scores

	City				Mann Whitney U
	Newcastle Fluoridated		Manchester Non-fluoridated		
	Number	%	Number	%	
Fluorosis TF Score					U = 264614, z =-13.025, p<0.0001
0	410	45%	638	73%	
1	355	39%	209	24%	
2	79	9%	16	2%	
3	53	6%	4	1%	
4	8	1%	0	0%	
5	1	0.1%	2	0.2%	
Total	**906**		**869**		

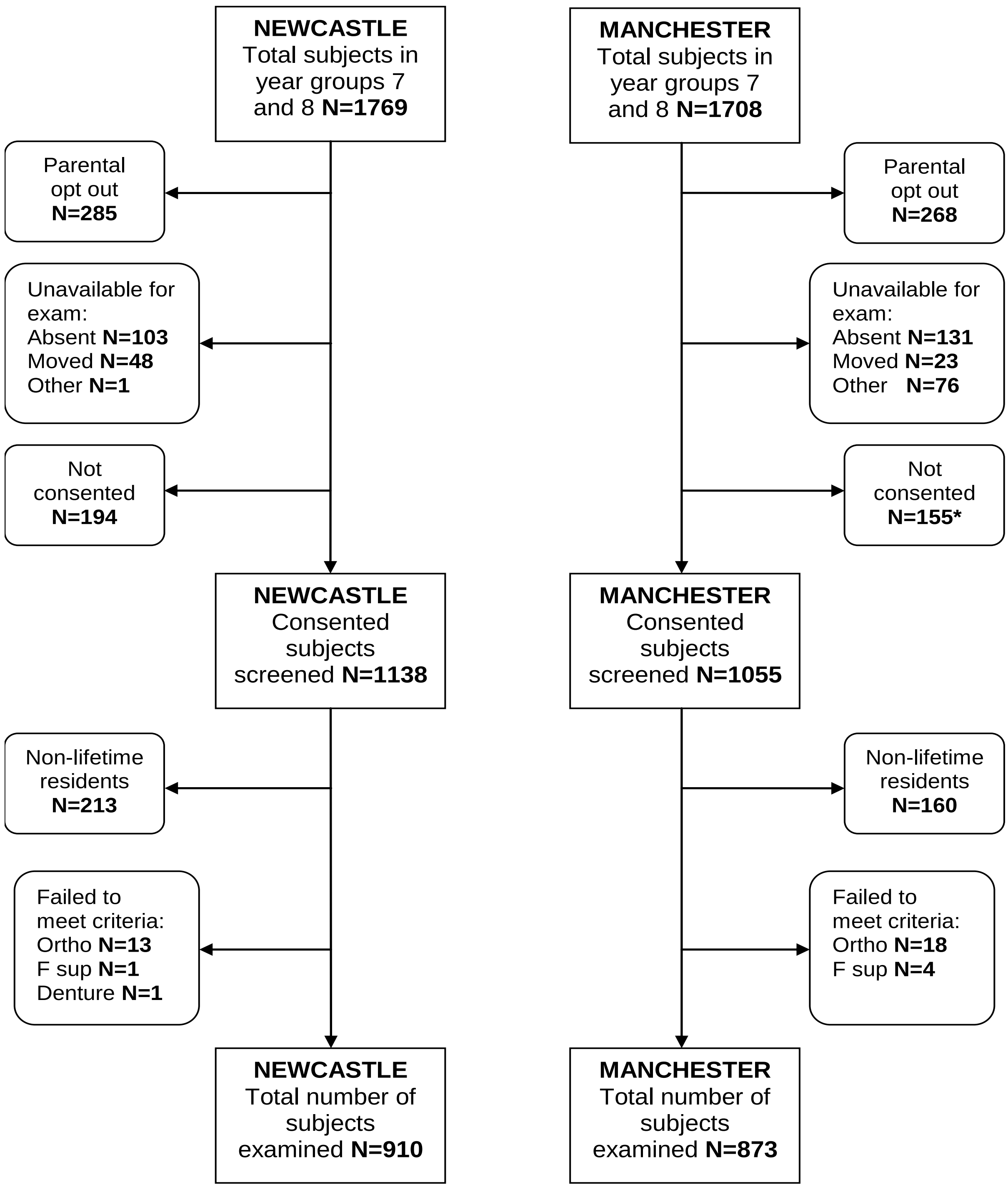
Table 8.9. Chi-squared tests and raw Odds Ratios for caries and fluorosis

	Condition	Manchester	Newcastle	χ^2 chi square	Odds Ratio
Clinical Caries: Threshold white spot lesion	No obvious Caries	133 (15%)	228 (25%)	P<0.001	Odds Ratio for Caries 1.9 times higher in Manchester
	Obvious Caries	740 (85%)	682 (75%)		
Clinical Caries: Threshold caries in dentine	No obvious Caries	473 (54%)	614 (68%)	P<0.001	Odds Ratio for Caries 1.8 times higher in Manchester
	Obvious Caries	400 (46%)	296 (32%)		
Photo Caries: Threshold white spot lesion	No obvious Caries	177 (20%)	298 (33%)	P<0.001	Odds Ratio for Caries 1.9 times higher in Manchester
	Obvious Caries	696 (80%)	612 (67%)		
Photo Caries: Threshold caries in dentine	No obvious Caries	475 (54%)	626 (69%)	P<0.001	Odds Ratio for Caries 1.9 times higher in Manchester
	Obvious Caries	398 (46%)	284 (31%)		
Fluorosis	No fluorosis	638 (73%)	410 (45%)	P<0.001	Odds Ratio for Fluorosis 3.3 times higher in Newcastle
	Fluorosis TF 1-5	231 (27%)	496 (55%)		
Fluorosis	Fluorosis TF 0-2	863 (99%)	844 (93%)	P<0.001	Odds Ratio for Fluorosis 10.5 times higher in Newcastle
	Fluorosis TF 3-5	6 (1%)	62 (7%)		

Table 8.10. Logistic regression models for caries and fluorosis.

Caries white spot lesion					
			95% CI for Odds Ratio		
	B (SE)	Sig	Lower	Odds Ratio	Upper
Included					
Constant	-4.511 (1.325)				
City	0.747 (0.122)	p<0.001	1.622	2.11	2.680
Age at Exam	0.357 (0.107)	p=0.001	1.160	1.430	1.762
IMD quintile 2	0.473 (0.158)	P=0.003	1.179	1.607	2.190
IMD quintile 3	0.783 (0.166)	p<0.001	1.580	2.188	3.028
IMD quintile 4	1.423 (0.193)	p<0.001	2.847	4.152	6.055
IMD quintile 5	1.487(0.187)	p<0.001	3.065	4.424	6.387
R^2=0.13 (Nagelkerke) Model χ^2 (6)= 165.47, p<0.0001 Hosmer and Lemeshow chi square = 11.733 sig = .164					
Caries into dentine					
			95% CI for Odds Ratio		
	B (SE)	Sig	Lower	Odds Ratio	Upper
Included					
Constant	-5.041 (1.151)				
City	0.610 (0.104)	P<0.001	1.500	1.840	2.258
Age at Exam	0.298 (0.093)	P=0.001	1.123	1.347	1.616
IMD quintile 2	ns	ns	-	-	-
IMD quintile 3	0.496 (0.169)	P=0.003	1.179	1.642	2.288
IMD quintile 4	0.878 (0.168)	P<0.001	1.730	2.406	3.345
IMD quintile 5	1.117 (0.166)	P<0.001	2.05	3.056	4.234
R^2=0.088 (Nagelkerke) Model χ^2 (6)= 119.3, p<0.0001 Hosmer and Lemeshow chi square = 4.804 sig = .778					
Fluorosis					
			95% CI for Odds Ratio		
	B (SE)	Sig	Lower	Odds Ratio	Upper
Included					
Constant	-1.42 (0.132)				
City	1.221 (0.103)	P<0.001	2.78	3.390	4.152
IMD quintile 1	0.411 (0.160)	P=0.01	1.101	1.508	2.065
IMD quintile 2	ns	ns	-	-	-
IMD quintile 3	ns	ns	-	-	-
IMD quintile 4	ns	ns	-	-	-
R^2= 0.11 (Nagelkerke). Model χ^2 (7)= 154.95, p<0.0001 Hosmer and Lemeshow chi square = 7.738 sig = .459					
Fluorosis TF3+					
			95% CI for Odds Ratio		
	B (SE)	Sig	Lower	Odds Ratio	Upper
Included					
Constant	-4.748 (0.468)				
City	2.344 (0.432)	P<0.001	4.467	10.424	24.325
IMD quintile 1	ns	ns	-	-	-
IMD quintile 2	ns	ns	-	-	-
IMD quintile 3	ns	ns	-	-	-
IMD quintile 4	ns	ns	-	-	-
R^2= 0.11 (Nagelkerke). Model χ^2 (5)= 57.094, p<0.0001Hosmer and Lemeshow chi square = 2.936 sig = .938					

Figure 8.1. Subject flow chart.



*Includes 2 subjects unable to provide consent

Figure 8.2. Components of DMFT over each quintile of deprivation depicted for each city

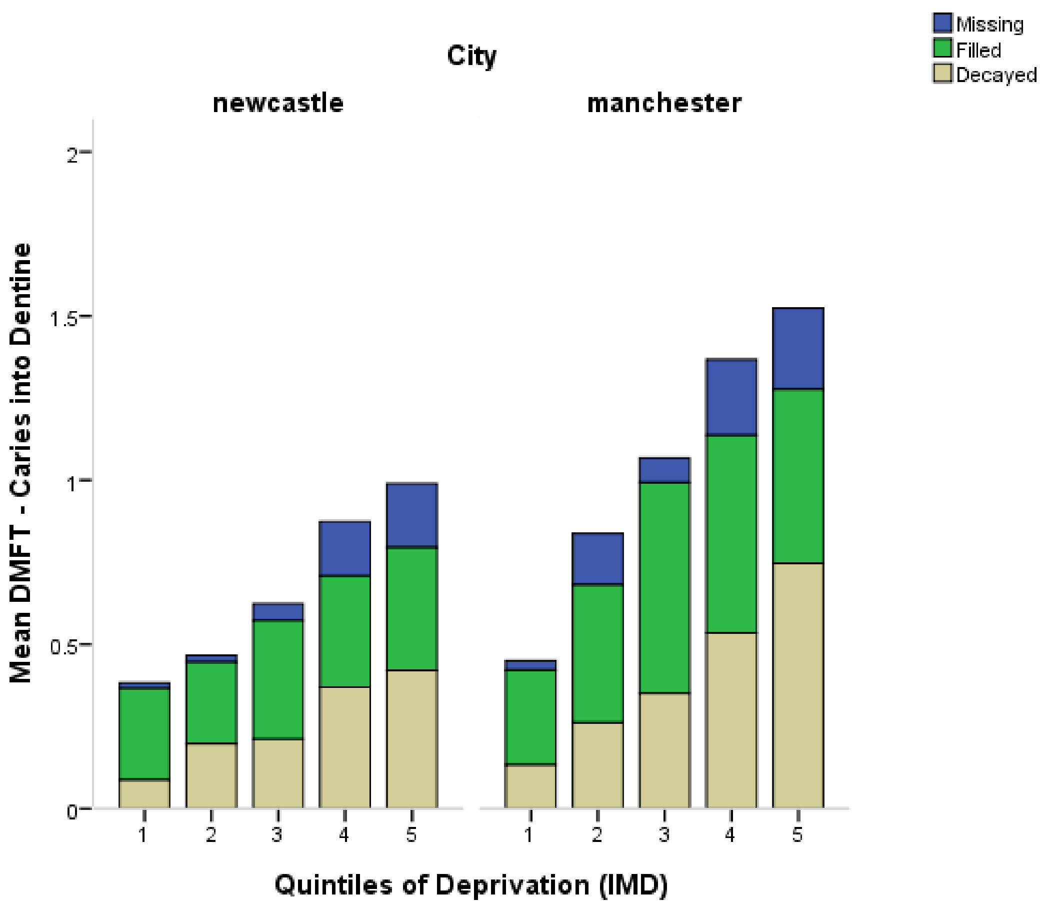
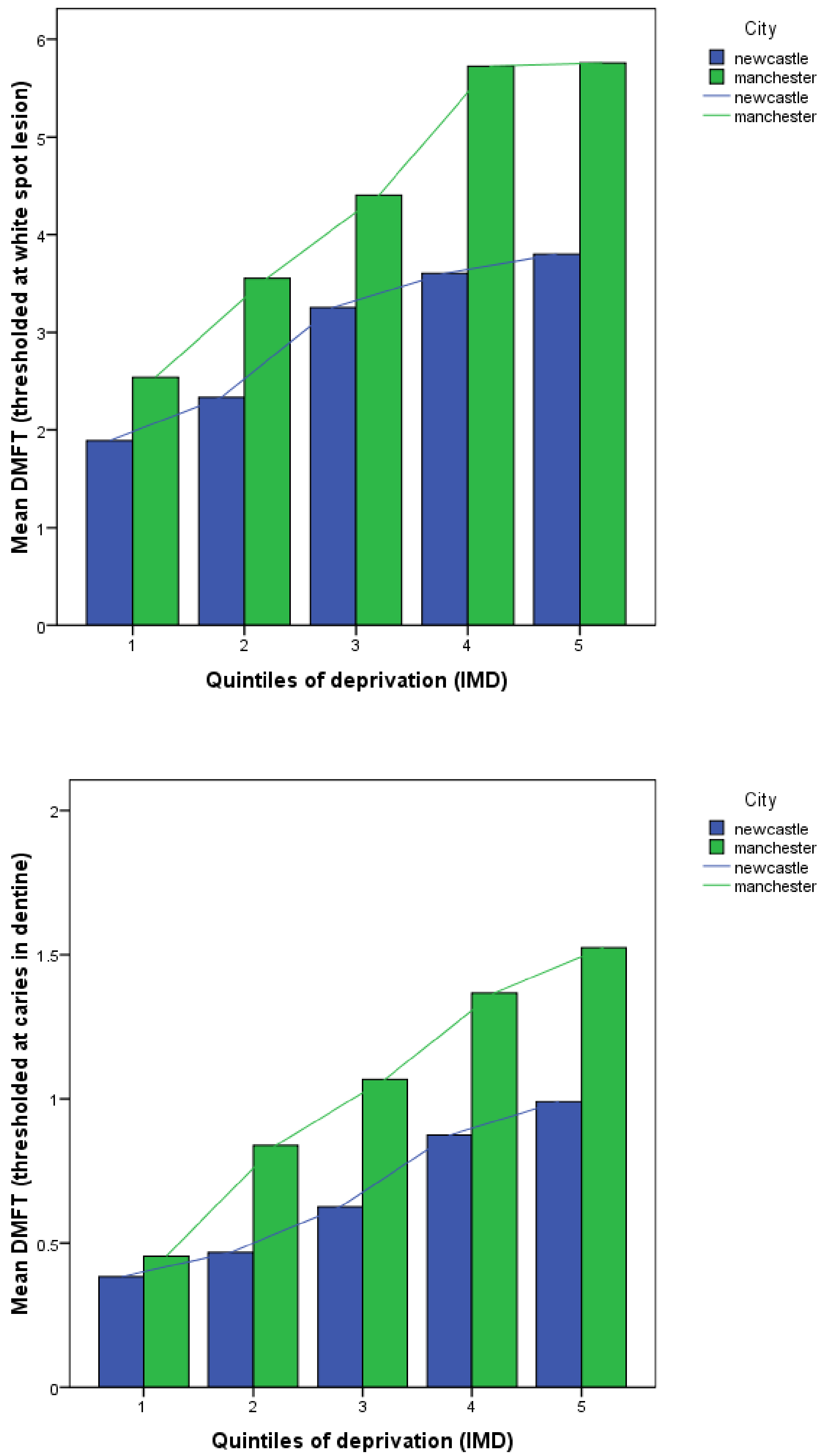
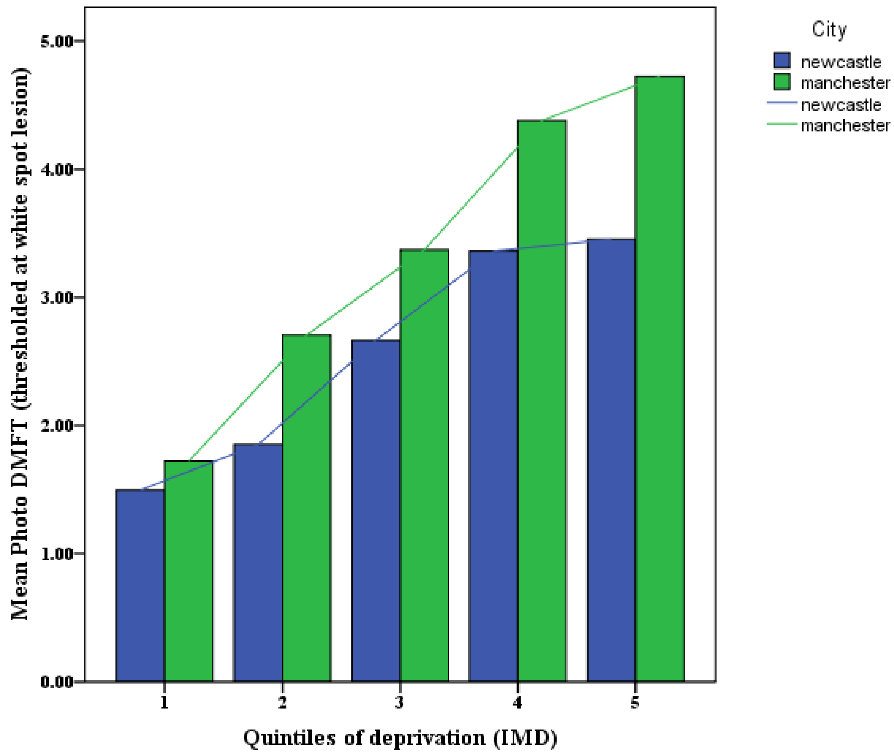


Figure 8.3. Bar chart of mean DMFT over each quintile of deprivation for each city demonstrating a reduction in social gradient for caries and deprivation in the fluoridated population for both clinical and photographic scores.




City
newcastle
manchester
newcastle
manchester
Mean Photo DMFT (thresholded at white spot lesion)
5.00
4.00
3.00
2.00
1.00
0.00
1
2
3
4
5
Quintiles of deprivation (IMD)

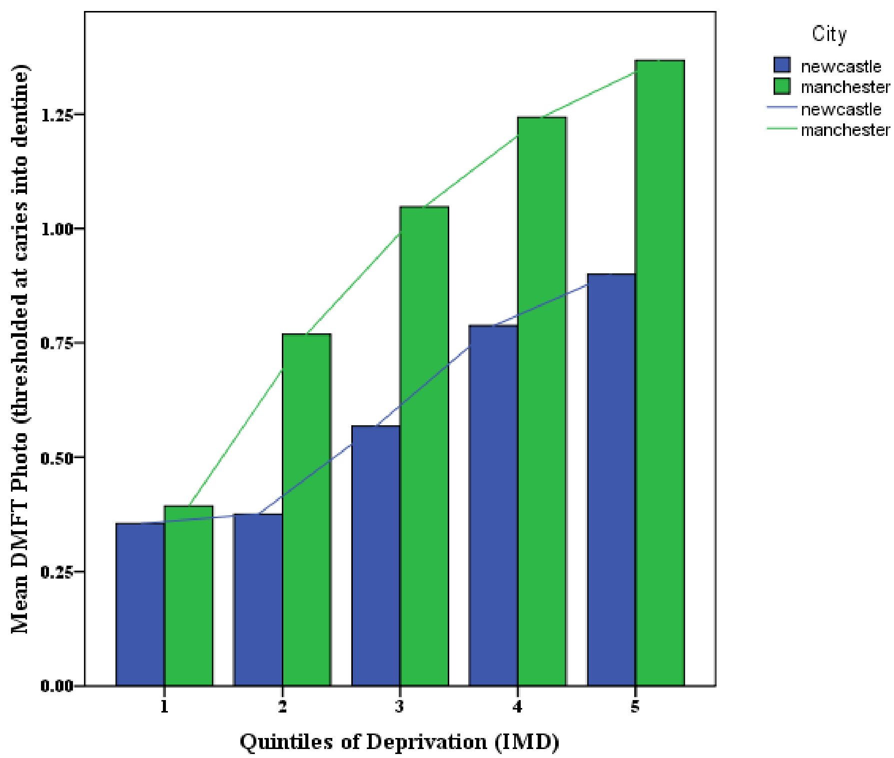
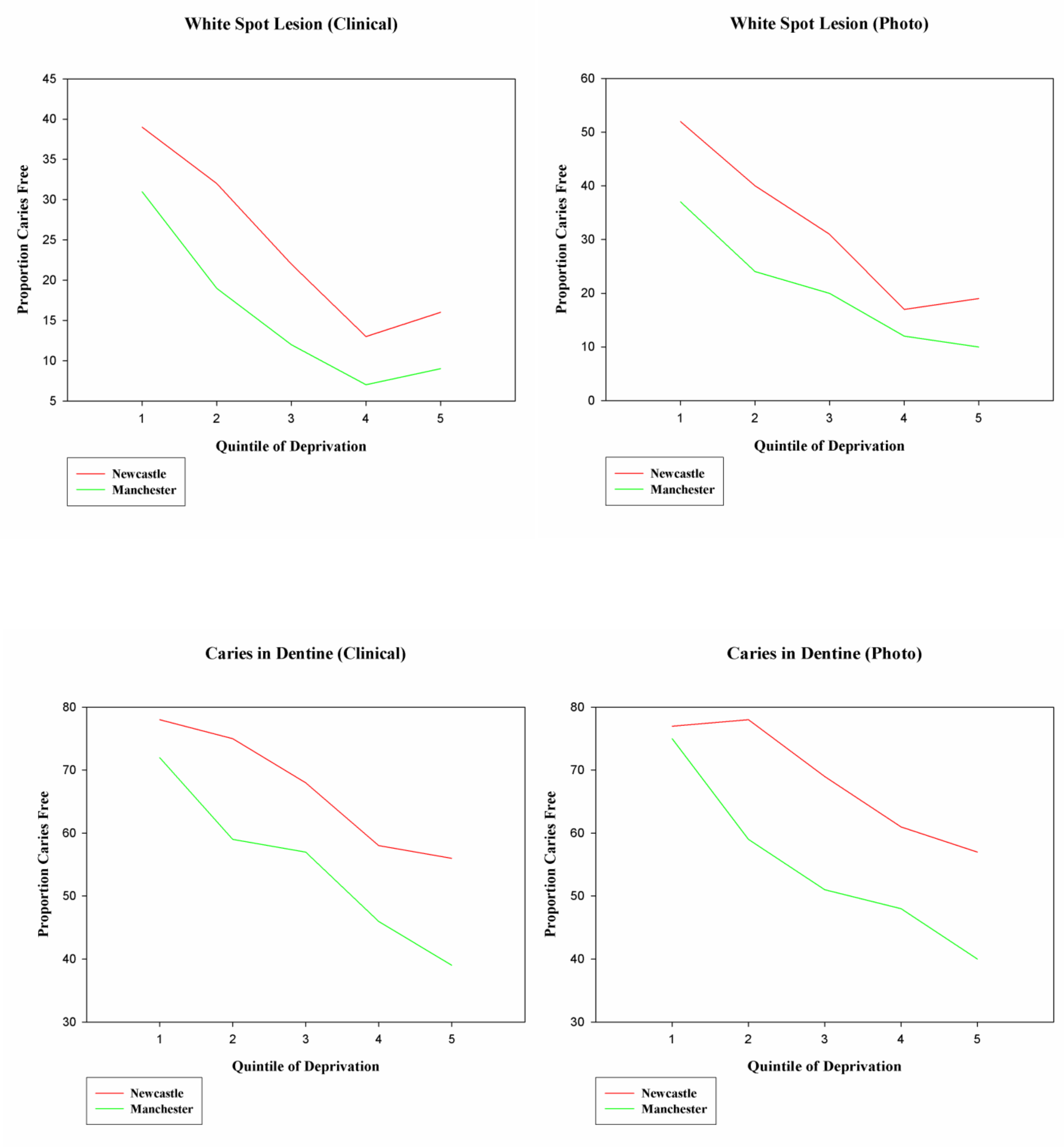

City
newcastle
manchester
newcastle
manchester
Mean DMFT Photo (thresholded at caries into dentine)
1.25
1.00
0.75
0.50
0.25
0.00
1
2
3
4
5
Quintiles of Deprivation (IMD)

Figure 8.4. Proportion of "caries free" subjects in each quintile of deprivation for each detection technique and threshold.



Chapter 9

Evaluating the use of Fluorescent Imaging for the Quantification of Dental Fluorosis.

Evaluating the use of Fluorescent Imaging for the Quantification of Dental Fluorosis**.**

M. G. McGrady[1], R. P. Ellwood[2], A. Taylor[2], A. Maguire[3], M. Goodwin[1], N. Boothman[1], I. A. Pretty[2]

[1]School of Dentistry, University of Manchester, England.
[2]Colgate Palmolive Dental Health Unit, University of Manchester, England.
[3]School of Dental Sciences, University of Newcastle, England.

Corresponding Author:
Michael G McGrady
Room 1.030 Coupland 3 Building
School of Dentistry
The University of Manchester
Higher Cambridge Street
Manchester
M13 9PL

Abstract

The quantification of fluorosis using fluorescence imaging (QLF) hardware and stain analysis software has been demonstrated in selected populations with good correlation between fluorescent image metrics and TF Index scores from photographs. The aim of this study was to evaluate the ability of QLF to quantify fluorosis in a population of subjects (aged 11-13) participating in an epidemiological caries and fluorosis survey in fluoridated and non-fluoridated communities in Northern England. Fluorescent images of the maxillary incisors were captured together with standardized photographs were scored blind for fluorosis using the TF Index. Subjects were excluded from the analysis if there were restorations or caries on the maxillary central incisors. Data were available for 1774 subjects (n=905 Newcastle, n=869 Manchester). The data from the fluorescence method demonstrated a significant correlation with TF Index scores from photographs (Kendall's tau = 0.332 $p<0.0001$). However, a number of additional confounding factors such as the presence of extrinsic stain or increased enamel translucency on some subjects without fluorosis or at low levels of fluorosis severity had an adverse impact on tooth fluorescence and hence the outcome variable. This in conjunction with an uneven distribution of subjects across the range of fluorosis presentations may have resulted in the lower than anticipated correlations between the fluorescent imaging metrics and the photographic fluorosis scores. Nevertheless, the fluorescence imaging technique was able to discriminate between a fluoridated and non-fluoridated population ($p<0.001$). Despite confounding factors the fluorescence imaging system may provide a useful objective, blinded system for the assessment of enamel fluorosis when used adjunctively with photographic scoring.

Introduction

The latter half of the 20th Century demonstrated a decline in the prevalence of dental caries through the use of optimally fluoridated community water supplies and fluoridated oral care products. However, this reduction in caries has also been associated with concerns regarding increased prevalence of dental fluorosis in both fluoridated and non-fluoridated communities (Clark 1994; Whelton, Crowley et al. 2004; Whelton, Crowley et al. 2006; Chankanka, Levy et al. 2010).

In the UK, a systematic review commissioned by the government known as the York Report (NHS-CRD 2000) set out to review the safety and efficacy of water fluoridation. The report stated the occurrence of fluorosis at water fluoride levels of 1ppm was found to be high (predicted 48%, 95% CI 40 to 57). Of this fluorosis, the proportion considered to be aesthetically objectionable was lower (predicted 12.5%, 95% CI 7.0 to 21.5). A study conducted in Newcastle upon Tyne (fluoridated) and Northumberland (non-fluoridated) found increased prevalence of fluorosis in the fluoridated area compared to the non-fluoridated area with similar figures for overall fluorosis prevalence quoted in the York Report but the prevalence of aesthetically objectionable fluorosis was lower at 3.4% (Tabari, Ellwood et al. 2000). The authors suggested reasons for similarities and differences in prevalence data from other studies (Hamdan and Rock 1991; Ellwood and O'Mullane 1995).

There are several possible explanations for the perceived increase in fluorosis prevalence. There could be a true increase in prevalence reflecting an increase in fluoride exposure from various sources of fluoride and an associated increased risk of fluorosis (Horowitz 1996). However, there are other plausible explanations that could explain the increase in prevalence. Traditionally, fluorosis has been assessed by the use of clinical indices such as Dean’s Index (Dean, Arnold et al. 1942) and the Thylstrup & Fejerskov (TF) Index (Thylstrup and Fejerskov 1978). The employment of clinical indices relies upon subjective assessment and interpretation of predetermined criteria which may impart bias. In light of this and despite a wealth of historical data there have been criticisms of the use of clinical indices in the York Report and elsewhere in the literature (Angmar-Mansson, de Josselin de Jong et al. 1994; Rozier 1994).

The choice of index may influence the investigation of fluorosis prevalence. Large volumes of data were collected through the work of H Trendley Dean utilizing an index that bore his name. This work subsequently led to the implementation of water fluoridation schemes (Dean 1934; Dean 1938; Dean 1942; Dean, Arnold et al. 1942). Despite criticism of Dean's Index (Clarkson 1989; Rozier 1994) it remains a popular index particularly in the United States. A major difference between Dean's Index and the TF Index is Dean's Index assesses teeth wetted by saliva and TF Index requires the drying of teeth prior to assessment. The latter technique highlights the presence of more mild presentations of fluorosis which in itself may result in an apparent increase in fluorosis prevalence and difficulties particularly when comparisons are made to historical data using alternative indices (Ellwood, O'Mullane et al. 1994).

An additional issue with clinical indices is the possibility of examiner bias. This may manifest through lack of blinding during assessment or variability in inter and intra-examiner agreement. There is also a phenomenon of personal thresholding particularly at low levels of fluorosis severity with differences in the application of diagnostic criteria (Ellwood, O'Mullane et al. 1994; Tavener, Davies et al. 2007). Attempts have been made to address some of the issues associated with the use of clinical indices. The remote scoring of standardized clinical photographs addresses issues pertaining to examiner blinding and facilitates the longitudinal assessment of fluorosis through the archiving of materials and repeatability of image capture (Cochran, Ketley et al. 2004; Cochran, Ketley et al. 2004). However, as this technique still fundamentally relies upon an examiner employing a subjective index, all of the confounding issues of a clinical index cannot be overcome. Consensus scoring of remote images (as in **Chapter 6** of this thesis) may address some issues relating to personal thresholding. A further consideration of the remote scoring technique is the viewing medium for image scoring. Magnification of images may increase the detection of milder forms of fluorosis and hence affect prevalence data relative to historical data and potential prospective data if viewing conditions are not carefully controlled.

The York Report and a report from the Medical Research Council that followed (MRC 2002) both stated the evidence base of studies on water fluoridation required improvement and were critical of the use of such subjective indices for the assessment of fluorosis. Future work should consider more reliable and objective means of quantifying fluorosis severity and for longitudinal monitoring.

Recent years have seen an emphasis on the detection and quantification of dental caries utilizing emerging technologies and diagnostic sciences (Pretty 2006). The development of caries detection systems with improved sensitivity and specificity over traditional visual and tactile techniques has invigorated the field of cariology enabling more preventative interventions to be used more successfully in preventing caries and the remineralization of early carious lesions. Unfortunately, the advances within cariology have not been reflected in the study of fluorosis where clinical indices still remain the gold standard. However, consideration has been made in the literature to the application of optical techniques employed in caries detection for assessment of fluorosis (Angmar-Mansson, de Josselin de Jong et al. 1994). One such technique is quantitative light induced fluorescence (QLF). QLF has been investigated as a means of detecting and quantifying early enamel carious lesions (van der Veen and de Josselin de Jong 2000; Angmar-Mansson and ten Bosch 2001) and has since been explored as a tool for quantifying dental plaque, tooth surface loss (erosion), extrinsic stain and for the quantification of fluorosis (Pretty, Edgar et al. 2002; Pretty, Edgar et al. 2004; Pretty, Tavener et al. 2006; Taylor, Ellwood et al. 2009).

Early work on the use of QLF in fluorosis quantification was encouraging (Pretty, Tavener et al. 2006). A novel software analysis technique was designed to overcome the difference in presentation of caries (discrete lesions) and fluorosis (diffuse lesions) and the resultant differences in fluorescence signal when using fluorescent imaging. On a selected population with milder forms of fluorosis, QLF achieved very good intra class correlation coefficients (ICC) when compared to the TF Index (Kendall’s Tau = 0.869). However, there were a number of confounding factors. There is an inherent difficulty in determining the potential of QLF as a means of quantifying fluorosis as there is no current acceptable gold standard with which to compare the output metrics of a fluorescent imaging system.

The ordinal data derived from a subjective clinical index cannot be easily compared to the continuous data generated from QLF. Hence the analysis could only determine the association between the two techniques, not true agreement. Furthermore, as QLF relies upon the detection of changes in fluorescence between “sound” and “unsound” enamel, any artefact inducing scattering of the reflected light from the tooth surface could result in a change in fluorescence and aberrant readings for fluorosis quantification. Such artefacts include presence of caries, extrinsic stain, restorations and non-fluorotic opacities. Nevertheless, QLF demonstrated in a small, selected population with a relatively limited range of fluorosis presentations the potential as a means of delivering a system for the reliable, objective quantification of enamel fluorosis.

Subsequent work aimed not only to refine the QLF system in fluorosis quantification by investigating alternate analysis techniques but also determining if QLF could discriminate between a wider range of presentations of fluorosis severity in larger populations with varying exposures to fluoride **(Chapter 6)**. The outcome of this work determined the use of a convex hull software algorithm was a more reliable means of quantifying fluorosis and that QLF could discriminate between populations with differing fluoride exposure and fluorosis severity. However, the confounding factors remained unresolved. Despite these limitations QLF still demonstrated potential as a means of objective, blinded quantification and a means of providing a system for longitudinal monitoring.

The aim of this study was to evaluate the use of fluorescent imaging for the quantification of dental fluorosis in an epidemiological survey and to determine the level of association with remote photographic scoring using a standard clinical index.

Subjects and Methods

Subjects were selected for this study had participated in an epidemiological survey looking at caries and fluorosis prevalence and severity in two areas in Northern England, Newcastle upon Tyne which has community water supplies fluoridated at an adjusted level of 1 mgF/L and Greater Manchester which receives non-fluoridated water supplies. The protocol for the study received ethical approval from the University of Manchester Committee on Ethics on Research on Human Beings (ref: 07952). The subjects were healthy males and females aged 11-13 years old who were life time residents of their locality. Written consent was obtained from the subjects after the parents or carers had been given two opportunities to object to their child's participation via a postal return of pre-prepared forms sent out prior to study recruitment.

Consented subjects were assigned a five-digit subject ID number based on the sequence of their recruitment. During the observational survey all subjects had standardized conventional digital photographs taken of the maxillary central incisors (Cochran, Ketley et al. 2004) after the teeth had been cleaned and dried for one minute with cotton wool rolls **(**Figure 9.1**)**. The images were exported to a computer and scored for fluorosis using the Thystrup & Fejerskov (TF) Index by a trained examiner (MGM) based at a remote location. The images were presented in a randomized and blind manner in order to ensure the examiner was unaware of the participant's residential status and fluoride content of community water supply.

Fluorescence Image Capture.

The imaging equipment comprised a custom-built stabilizing unit, comprising an adjustable head and chin support and a camera focus platform connected to a high-resolution 3 CCD camera (Jai M91P, Jai Corp., Copenhagen, Denmark) and illuminator (a custom made LED array with variable illumination emitting light with peak source at 405-nm). The platform enabled the camera to be repositioned and focussed while the subject remained static (Figure 9.2).

Software

A convex hull analysis software package originally designed to quantify stain on teeth was utilized (Taylor, Ellwood et al. 2009). The software was designed to detect diffuse areas on the tooth surface using an algorithm based on a convex hull to detect and quantify the diffuse areas of hypomineralization associated with fluorosis. The application of this methodology has been described in **Chapter 6** of this thesis.

Statistical Analysis

The data for the photographic TF index scores from the epidemiological survey were entered into the Statistical Package for Social Sciences (SPSS 16.0) along with the metrics from the analysis of the fluorescent images using convex hull software. For each subject, the higher of the two scores on the maxillary central incisors was used in the statistical analysis. Correlation coefficients between the photographic scores and the output from the software analyses were determined using for comparison with the metrics of ΔF_{ch}, $Area_{ch}$ and ΔQ_{ch}.

Results

Once data cleaning had been completed data were available for 1774 (Newcastle 905, Manchester 869) subjects with QLF images of the maxillary central incisors and corresponding photographic fluorosis scores using TF index. This data is presented in Table 9.1 demonstrating frequency counts for fluorosis severity. As dental fluorosis is not endemic in the UK, the data did not present a uniform distribution of presentations of severity, with 59% of the patients not having the condition and 32% of subjects having fluorosis with a severity of TF1 when assessed by photographic scoring using a standard clinical index. The data were analyzed to determine the association between the photographic scores and the QLF metrics. The data demonstrated an increase in mean value for each QLF metric as the fluorosis severity increased (Table 9.2). Intra class correlation coefficients were calculated for each of the QLF output metrics (ΔF_{ch}, $Area_{ch}$ and ΔQ_{ch}) and are described in Table 9.2. Each of the QLF metrics demonstrated significant associations with the photographic scores for fluorosis with Kendall's tau values of 0.342, 0.282 and 0.332 for area, ΔF_{ch} and ΔQ_{ch} respectively. The metric for $Area_{ch}$ had the highest association with the photographic scores, but in terms of fluorosis quantification, the QLF metric for ΔQ_{ch} holds the most relevance as it is a composite of the degree of fluorescence loss and a measure of the area of tooth surface involved.

A boxplot of ΔQ_{ch} against TF score (Figure 9.3) demonstrates the increase in magnitude of the QLF metric as the fluorosis severity increases. It also revealed a large number of outliers in the dataset particularly for lower severities of fluorosis. Outliers were identified and the QLF images and photographs for these subjects re-examined to find possible explanations for the results. The presence of caries, restorations and demarcated opacities are known to be confounders for QLF and most outliers were found to demonstrate one or more of these characteristics. A summary of additional confounding factors and the associated frequency counts from subjects with TF0 and TF1 are shown in Table 9.3. The presence of extrinsic stain was the most common additional confounding factor identified (16 subjects) but there were more subjects (30) where no plausible explanation for the QLF outcome could be provided.

The data was then examined to determine if the two populations (fluoridated and non-fluoridated) could be separated for fluorosis prevalence using the fluorescent imaging technique. Ranks and sum of ranks for each QLF metric were calculated for both cities and are displayed in Table 9.4. Non-parametric analysis using Man Whitney U tests demonstrated significant differences between the fluoridated and non-fluoridated population for each of the QLF metrics ($p<0.001$).

The data was exported to Stata (release 11, StataCorp, TX, USA) and a receiver operating characteristic (ROC) curve produced using a classification model for the QLF metric output ΔQ_{ch} and a classifier boundary, or threshold, for fluorosis (TF photo score) of ≤ 2 and ≥ 3. The ROC curve is illustrated in Figure 9.4. The Area under the curve (AUC) was 0.9164 suggesting an excellent level of accuracy.

Contingency tables for subjects with or without fluorosis for the QLF metric ΔQ_{ch} and photographic TF scores ≤ 2 and ≥ 3 are shown in Table 9.5. Both methodologies demonstrate differences between the fluoridated and non- fluoridated populations. The proportion of subjects with fluorosis differed between the two methodologies. The proportion for photographic scores was 1% in Manchester and 7% Newcastle, whereas for ΔQ_{ch} the proportions were 10% and 19% in Manchester and Newcastle respectively. The results suggested the QLF technique was able to differentiate between the fluoridated and non-fluoridated populations. However, whilst the direction of difference was the same the difference in magnitude of the proportions between the two methodologies highlighted issues relating to the sensitivity and specificity of fluorosis detection.

Discussion

The purpose of this study was to use the QLF system within a standard epidemiological survey. The earlier work of Pretty et al (Pretty, Tavener et al. 2006) and work described in **Chapter 6** identified strengths and weaknesses of fluorosis quantification by fluorescent imaging techniques. The encouraging results from the early work on intra class correlations between the QLF metrics and TF scores and the ability to detect differences in populations with different fluoride exposures gave justification for incorporating the system into an epidemiological survey. However, many of the issues raised by Pretty et al (Pretty, Tavener et al. 2006) remained unresolved.

The lack of an appropriate gold standard for comparison with the QLF metrics gave rise to statistical and interpretive problems as the data from the TF index is on an ordinal scale from 0 to 9 whereas the output from the QLF metrics generates continuous data. The consequence is there are no appropriate statistical methods to assess agreement. Hence, the use of correlations during analysis demonstrates the association between the outcomes which should not be interpreted as agreement.

Choice of gold standard is not a unique issue to fluorosis quantification. QLF and other fluorescent imaging techniques have been used to detect caries with similar issues regarding agreement between outcome measures (ten Bosch and Angmar-Mansson 2000). In the case of caries detection, gold standards exist through histological examination using light microscopy and microradiography. These techniques have enabled the development of more robust assessment of agreement with QLF metrics relating to caries detection (Kuhnisch, Ifland et al. 2006) with cut off thresholds for the fluorescence devices. The validation of such devices for caries detection is an evolving subject influenced by the tooth surface under investigation and has been facilitated by the existence of more appropriate gold standards. The absence of an appropriate gold standard for fluorosis quantification resulted in a cut off threshold for ΔQ_{ch} being determined from the ROC curve. This should not be interpreted as a transferable threshold for QLF analysis of other populations as it was not validated.

The decision to use the TF Index for fluorosis scoring was influenced by the index being based on the histological features associated with the presentation of the condition (Thylstrup and Fejerskov 1978). However, fundamental differences exist between the aspects of the condition assessed by QLF and the TF Index. The former detects fluorosis over the whole tooth surface through fluorescence loss in image pixels whereas the latter assesses fluorosis not only from the clinical manifestations of histological changes but also from the patterns of presentation such as diffuse lines and confluent areas. Hence, the TF Index has no direct means of assessing the area of tooth surface involved. It is therefore interesting to find from the results of this study the QLF metric for area has the strongest correlation with the TF scores.

An inherent limitation of QLF is the inability to differentiate fluorescence loss as a result of fluorosis, other forms of developmental enamel defects and tooth surface phenomena such as enamel fractures and extrinsic stain. There is evidence to suggest that the use of computer software techniques may facilitate this process (McGrady, Browne et al. 2008) but this would involve more complicated image processing and tooth mapping prior to analysis.

Conclusions

The results of this study suggest that QLF has the ability to reliably quantify fluorosis in an epidemiological setting, albeit assisted by clinical diagnosis. In addition, QLF was able to discriminate between fluoridated and non-fluoridated populations. The intra class correlation coefficients are lower than those obtained by Pretty et al (Pretty, Tavener et al. 2006) and those obtained from the work in **Chapter 6.** However, these associations are still significant and it should be stated that through each iterative stage of QLF evaluation the study populations have become larger, less selected, have demonstrated greater variety of fluorosis presentation and the potential for more confounding factors. Improved image mapping and software analysis may reduce these phenomena. Fluorescent imaging techniques such as QLF appear to have a high sensitivity but reduced specificity when employed in the detection and quantification of fluorosis impacting on the potential for these technologies to act as diagnostic tools for this condition. However, despite these limitations, QLF has the potential to monitor fluorosis longitudinally at both a population and individual level.

Acknowledgements

The authors wish to thank the pupils and staff at the schools who participated, Dianne Tabari, Deborah Howe and Valerie Dalton from Newcastle Primary Care Trust for their support and assistance during this project. The computer software was created by Dr Andrew Taylor of the Dental Health Unit. Dr Pretty is funded by a Clinician Scientist Award from the National Institute for Health Research (UK). This research was supported by Colgate Palmolive Dental Health Unit, Manchester, UK.

References

Angmar-Mansson, B., E. de Josselin de Jong, et al. (1994). "Strategies for improving the assessment of dental fluorosis: focus on optical techniques." Adv Dent Res **8**(1): 75-9.

Angmar-Mansson, B. and J. J. ten Bosch (2001). "Quantitative light-induced fluorescence (QLF): a method for assessment of incipient caries lesions." Dentomaxillofac Radiol **30**(6): 298-307.

Chankanka, O., S. M. Levy, et al. (2010). "A literature review of aesthetic perceptions of dental fluorosis and relationships with psychosocial aspects/oral health-related quality of life." Community Dent Oral Epidemiol **38**(2): 97-109.

Clark, D. C. (1994). "Trends in prevalence of dental fluorosis in North America." Community Dent Oral Epidemiol **22**(3): 148-52.

Clarkson, J. (1989). "Review of terminology, classifications, and indices of developmental defects of enamel." Adv Dent Res **3**(2): 104-109.

Cochran, J. A., C. E. Ketley, et al. (2004). "A comparison of the prevalence of fluorosis in 8-year-old children from seven European study sites using a standardized methodology." Community Dent Oral Epidemiol **32 Suppl 1**: 28-33.

Cochran, J. A., C. E. Ketley, et al. (2004). "Development of a standardized method for comparing fluoride ingested from toothpaste by 1.5-3.5-year-old children in seven

European countries. Part 2: Ingestion results." Community Dent Oral Epidemiol **32 Suppl 1**: 47-53.

Cochran, J. A., C. E. Ketley, et al. (2004). "A standardized photographic method for evaluating enamel opacities including fluorosis." Community Dent Oral Epidemiol **32 Suppl 1**: 19-27.

Dean, H. T. (1934). "Classification of mottled enamel diagnosis." J Am Dent Assoc **21**(1421-6).

Dean, H. T. (1938). "Endemic Fluorosis and its relation to dental caries." Public Health report **53**: 1443-1452.

Dean, H. T. (1942). "The investigation of physiological effects of the epidemiological method." Fluoride and Dental Health **American Association for the Advancement of Science**.

Dean, H. T., F. A. Arnold, et al. (1942). "Domestic water and dental caries. V. Additional studies of the relation of fluoride domestic waters to dental caries experience in 4,425 white children aged 12-14 years of 13 cities in 4 states." Public Health Rep **57**: 1155-79.

Ellwood, R., D. O'Mullane, et al. (1994). "A comparison of information recorded using the Thylstrup Fejerskov index, Tooth Surface Index of Fluorosis and Developmental Defects of Enamel index." Int Dent J **44**(6): 628-36.

Ellwood, R. P. and D. M. O'Mullane (1995). "Dental enamel opacities in three groups with varying levels of fluoride in their drinking water." Caries Res **29**(2): 137-42.

Hamdan, M. and W. P. Rock (1991). "The prevalence of enamel mottling on incisor teeth in optimal fluoride and low fluoride communities in England." Community Dent Health **8**(2): 111-9.

Horowitz, H. S. (1996). "The effectiveness of community water fluoridation in the United States." J Public Health Dent **56**(5 Spec No): 253-8.

Kuhnisch, J., S. Ifland, et al. (2006). "Establishing quantitative light-induced fluorescence cut-offs for the detection of occlusal dentine lesions." Eur J Oral Sci **114**(6): 483-8.

McGrady, M. G., D. Browne, et al. (2008). "Differentiation of demarcated enamel opacities from fluorosis using quantitative light-induced fluoroescence." Caries Research **42**: 213.

MRC (2002). Medical Research Council Working Group Report. Water fluoridation and health. London, MRC.

NHS-CRD (2000). A Systematic Review of Public Water Fluoridation. York, The University of York, NHS Centre for Reviews and Dissemination (Report 18).

Pretty, I. A. (2006). "Caries detection and diagnosis: novel technologies." J Dent **34**(10): 727-39.

Pretty, I. A., W. M. Edgar, et al. (2002). "QLF quantification of plaque in a re-growth clinical trial." Caries Res **36**(3): 214-5.

Pretty, I. A., W. M. Edgar, et al. (2004). "The validation of quantitative light-induced fluorescence to quantify acid erosion of human enamel." Arch Oral Biol **49**(4): 285-94.

Pretty, I. A., J. A. Tavener, et al. (2006). "Quantification of dental fluorosis using fluorescence imaging." Caries Res **40**(5): 426-34.

Rozier, R. G. (1994). "Epidemiologic indices for measuring the clinical manifestations of dental fluorosis: overview and critique." Adv Dent Res **8**(1): 39-55.

Tabari, E. D., R. Ellwood, et al. (2000). "Dental fluorosis in permanent incisor teeth in relation to water fluoridation, social deprivation and toothpaste use in infancy." Br Dent J **189**(4): 216-20.

Tavener, J., R. M. Davies, et al. (2007). "Agreement amongst examiners assessing dental fluorosis from digital photographs using the TF index." Community Dent Health **24**(1): 21-5.

Taylor, A. M., R. P. Ellwood, et al. (2009). "Quantitative stain detection in vivo using fluorescent imaging." J Dent **37**(5): 397-405.

ten Bosch, J. J. and B. Angmar-Mansson (2000). "Characterization and validation of diagnostic methods." Monogr Oral Sci **17**: 174-89.

Thylstrup, A. and O. Fejerskov (1978). "Clinical appearance of dental fluorosis in permanent teeth in relation to histologic changes." Community Dent Oral Epidemiol **6**(6): 315-28.

van der Veen, M. H. and E. de Josselin de Jong (2000). "Application of quantitative light-induced fluorescence for assessing early caries lesions." Monogr Oral Sci **17**: 144-62.

Whelton, H., E. Crowley, et al. (2006). "Dental caries and enamel fluorosis among the fluoridated population in the Republic of Ireland and non fluoridated population in Northern Ireland in 2002." Community Dent Health **23**(1): 37-43.

Whelton, H., E. Crowley, et al. (2004). "Dental caries and enamel fluorosis among the fluoridated and non-fluoridated populations in the Republic of Ireland in 2002." Community Dent Health **21**(1): 37-44.

Table 9.1. Frequency counts of subjects at each level of TF Index score

Photographic TF Score	City (frequency counts)				Total
	Newcastle		Manchester		
	n	%	n	%	
0	409	45%	638	73%	1047
1	355	39%	209	24%	564
2	79	9%	16	2%	95
3	53	6%	4	1%	57
4	8	1%	0	0%	8
5	1	0.1%	2	0.2%	3
Total	905		869		1774

Table 9.2. Intra Class Correlation Coefficients for QLF metrics and mean metric values for each TF Index score

QLF METRIC (mean)	TF SCORE						Spearman's rho	Kendall's tau b
	0	1	2	3	4	5	P<0.0001	
$\mathbf{Area}_{ch}$	0.070	0.097	0.177	0.248	0.317	0.402	.421	.342
$\mathbf{\Delta F_{ch}}$	0.043	0.047	0.058	0.070	0.086	0.108	.349	.282
$\mathbf{\Delta Q_{ch}}$	0.004	0.005	0.011	0.018	0.034	0.046	.410	.332

Table 9.3. Description and frequency of subjects with additional compounding factors

Confounding Factor	**Number of subjects**	
	TF0	**TF1**
Extrinsic stain	13	3
Enamel erosion	1	-
Translucent enamel	2	-
Enamel fractures	2	-
Missed demarcated opacity	3	7
Unknown	14	16
Total	**35**	**26**

Table 9.4. Comparison of QLF metrics between cities.

QLF Metric	City	Mean Rank	Sum of Ranks	Mann Whitney U	Sig (2-tailed)
$Area_{ch}$	Newcastle (N=905)	1014.67	918274.00	278136.00	P<0.001
	Manchester (N=869)	755.06	656151.00		
ΔF_{ch}	Newcastle (N=905)	976.62	883843.00	312576.00	P<0.001
	Manchester (N=869)	794.69	690582.00		
ΔQ_{ch}	Newcastle (N=905)	1006.98	911320.00	285090.00	P<0.001
	Manchester (N=869)	763.07	663105.00		

Table 9.5. Contingency Table of subjects with and without fluorosis as determined by Δ Q (QLF) and photographic TF score

	Condition	Manchester (869)	Newcastle (905)	χ^2 chi square
Fluorosis ΔQ_{ch}	No Fluorosis	783 (90%)	731 (81%)	χ^2 (1)= 31.735, P<0.0001
	Fluorosis	86 (10%)	172 (19%)	
Fluorosis photo	Fluorosis TF 0-2	863 (99%)	843 (93%)	χ^2 (1)= 45.640, P<0.0001
	Fluorosis TF 3-5	6 (1%)	62 (7%)	

Figure 9.1. Photographic image of maxillary incisors using standardized technique

Figure 9.2. Image of bespoke QLF array together with geometry stabilizing equipment

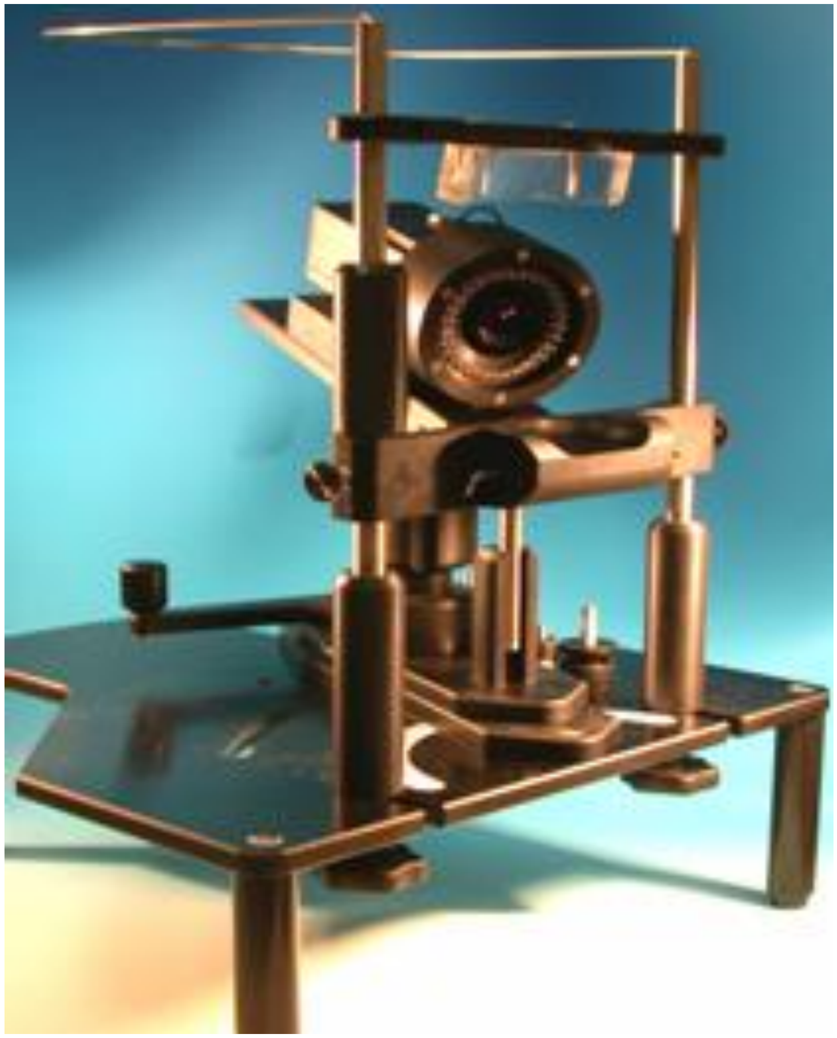


Figure 9.3. Boxplot of QLF metric for Delta Qch against photographic TF Index score (with subject outliers)

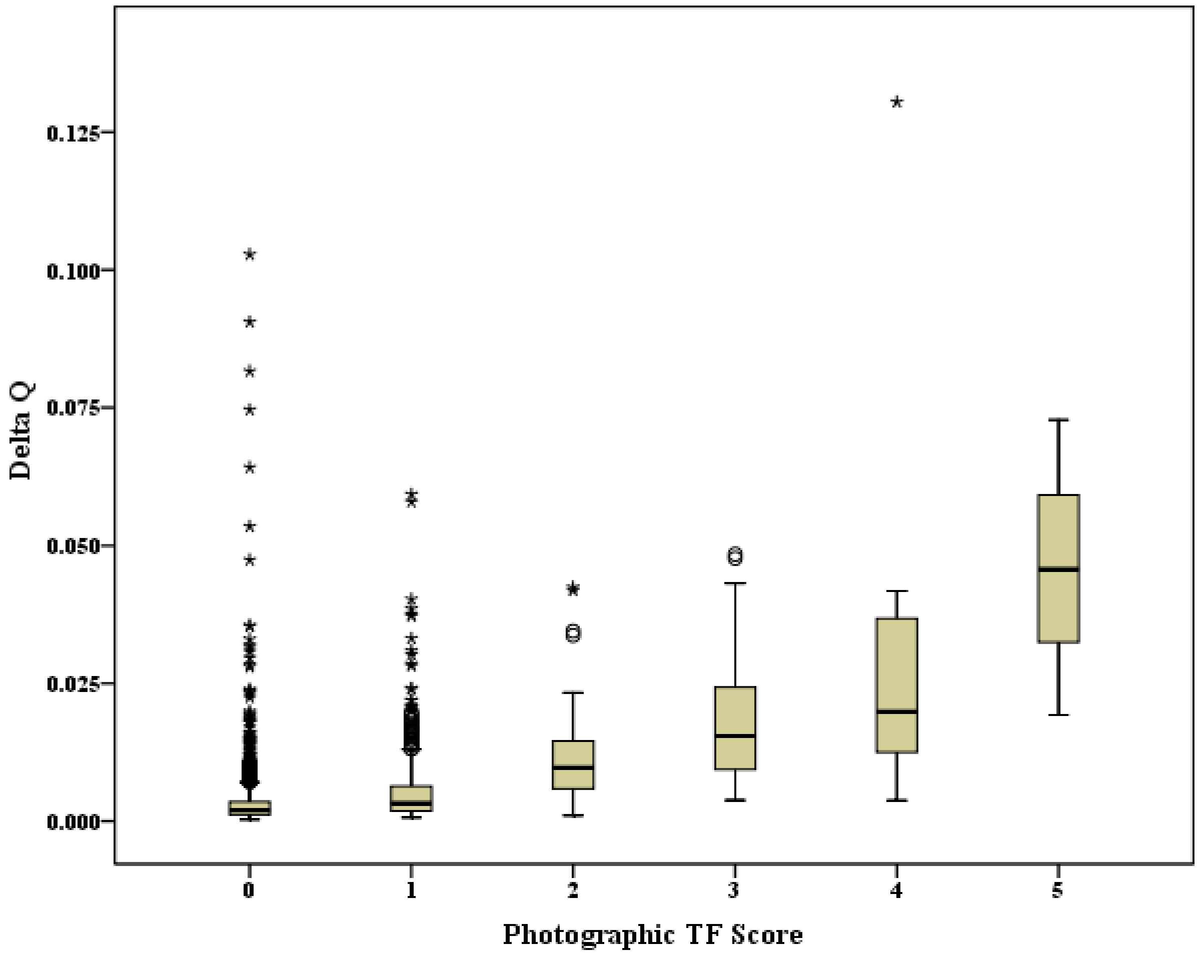
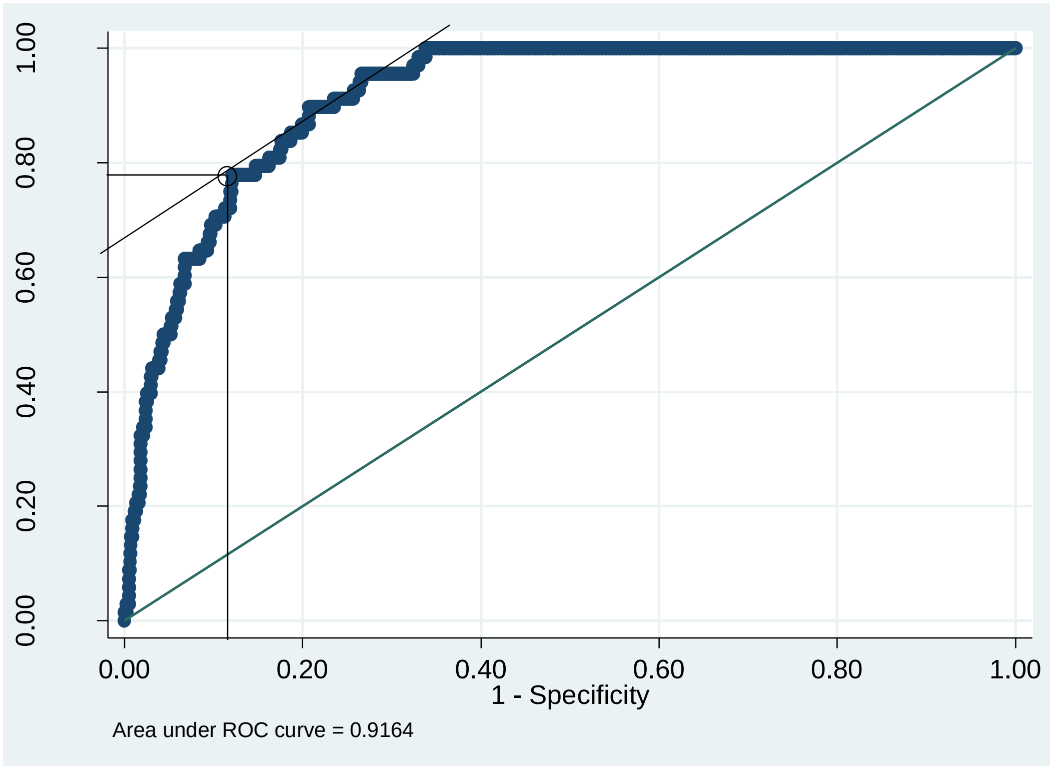


Figure 9.4. ROC curve for QLF fluorosis detection



Further Studies in Caries and Fluorosis

Chapter 10

Summary

Fluoride has been used extensively in dentistry for caries prevention with empirical evidence accumulated by eminent figures such as McKay, Black and Dean leading to an understanding of the risks of dental fluorosis and benefits of caries reduction and the implementation of community water fluoridation schemes. The advent of fluoridated dentifrice and the increasing view that the mode of action of fluoride is predominantly topical has questioned the continued use of community water fluoridation as an appropriate vehicle for delivering fluoride.

Systemic Reviews such as the York Report (NHS-CRD 2000) and a report from the MRC (MRC 2002) have examined the evidence base for community water fluoridation. Despite the conclusion that water fluoridation and fluoridated dentifrice appear to provide additional caries prevention over the use of fluoridated dentifrice alone there were shortcomings in the evidence base. Future work needed to address issues surrounding the methodologies for caries and fluorosis detection particularly issues pertaining to examiner blinding and the use of subjective clinical indices.

The projects in this thesis centered on the development and evaluation of methodologies for dental caries and fluorosis assessment. The driver for this work was to address deficiencies in the evidence base highlighted in the York Report and MRC report.

Traditional clinical indices are subjective and may lack sensitivity to facilitate reliable assessment. ICDAS, whilst still ultimately a subjective index, may provide an opportunity to report caries prevalence and severity in a population in a structured and potentially more sensitive manner than more traditional indices used in epidemiological surveys. Issues related to examiner blinding are found with assessment of dental caries using clinical indices. The utilization of intra-oral images with remote blind scoring provided an opportunity to address examiner bias.

Fluorescence imaging technology such as quantitative light-induced fluorescence (QLF) has demonstrated the ability to detect and quantify dental caries (van der Veen and de Josselin de Jong 2000). Modifications to this system, in particular the computer software and analysis techniques have provided an opportunity to evaluate QLF for the detection and quantification of dental fluorosis (Pretty, Tavener et al. 2006). This would facilitate the objective quantification of fluorosis and address issues associated with examiner blinding and bias.

Thailand Project

The project in Chiang Mai, Thailand was conducted in Collaboration with the Faculty of Dentistry, University of Chiang Mai and had two main objectives, firstly an epidemiological survey to identify populations with differing exposures to fluoride and determine the severity of dental fluorosis in these populations; secondly to determine if the ability of QLF to detect a dose response to changes in fluoride exposure from water sources when compared to a randomized blinded score of TF index obtained from standardized photographs of the maxillary central incisors.

The subjects in the study were male and female life time residents of their locality aged between 8 and 13 years old. The aim was to determine the fluoride content of the water supply in determining risk factors for fluorosis. Endemic fluorosis is a problem in the region of Chiang Mai owing to the extensive use of high fluoride groundwater and as a result efforts have been made to educate locals and to provide low fluoride drinking water. However, dietary patterns and food preparation methods mean that despite access to low fluoride drinking water, many individuals still utilize groundwater for food preparation. This fact, in conjunction with rice being a staple of the diet, results in increased exposure to high levels of fluoride. For this reason subjects were asked to provide water samples for drinking water and cooking water for analysis to ascertain fluoride content.

Data generated from the cooking water were used to assign the subjects into groups (water fluoride intervals) based on the frequency distribution of cooking water fluoride content creating five (5) intervals for cooking water and four (4) corresponding intervals for drinking water. This was owing to the fact there was a wider range and variation in the fluoride content of the cooking water compared to the drinking water and as such, the water used for cooking and food preparation potentially posed the greater risk for fluorosis. The recruitment process continued until there was balance between the groups for cooking water fluoride content. The water interval groups are described in Table 10.1.

Table 10.1. Distribution of subjects in water interval groups for cooking water and drinking water.

Cooking Water Interval Data (ppmF)	Number of Subjects	Drinking Water Interval Data (ppmF)	Number of Subjects
<0.20	103	<0.20	210
0.2 to 0.59	111	0.2 to 0.59	218
0.6 to 0.89	123	0.6 to 0.89	63
0.9 to 1.59	111	0.9+	69
1.6+	112	-	-
	560		560

Recruited subjects had a structured interview to explore previous cooking and drinking water use, exposure to fluoride, infant feeding patterns and oral hygiene practices before having standardized photographs and QLF images taken of the maxillary central incisors. Data from 560 subjects were available for analysis (298 M, 262F). A weighted kappa of 0.80 (SE 0.05, 95% CI 0.71, 0.89) was obtained for repeat, remote, photographic scores. The overall prevalence of fluorosis in the study population was 70.9% with a prevalence of aesthetically significant fluorosis (TF 3+) of 16.8%. The prevalence of fluorosis among subjects consuming drinking and cooking water <0.9ppm fluoride was 60.6% (10.1% for TF 3+). The prevalence of fluorosis among subjects consuming drinking and cooking water >0.9ppm fluoride was 85.1% (16.8% for TF 3+).

Data generated from subject interviews revealed drinking and cooking water at age 3, water used for infant formula and water used for preparing infant food all demonstrated an increase in fluorosis severity with increase in water fluoride level ($p<0.001$). Interview data for oral hygiene practices and infant feeding was deemed to be unreliable owing to incomplete capture and recall bias.

The Odds ratio for the presentation of aesthetically significant fluorosis (TF index 3+) was 3.34 (robust SE 1.22; 95%CI 1.52, 7.04) for subjects consuming drinking water with fluoride content equal to or greater than 0.9pmm relative to drinking water consumption with less than 0.2ppm fluoride. The Odds Ratio for the presentation of aesthetically significant fluorosis was 5.54 (robust SE 3.01; 95%CI 1.91, 16.04) for subjects consuming cooking water with a fluoride content equal to or greater than 1.6ppm relative to cooking water consumption with less than 0.2ppm fluoride. Probability estimates for the presentation of aesthetically significant fluorosis (TF index 3+) were 0.53 for exposure to high fluoride drinking (≥0.9ppm) and cooking water (≥1.6ppm). High fluoride cooking and drinking water were associated with an increased risk of aesthetically significant dental fluorosis. Fluoride levels in current drinking and cooking water were strongly correlated with fluorosis severity.

The evaluation of QLF in discriminating between the population water interval groups was performed by analyzing the QLF output metrics against the TF Index scores generated by remote scoring of the standardized photographs. In addition, two separate software analysis techniques were evaluated for the QLF images. The existing technique employed by Pretty et al (Pretty, Tavener et al. 2006) employed a blur technique calculating the average of pixels within a matrix of pre-determined size replacing each point in the image with the average value of the surrounding pixels. The greater the size of the matrix, the larger the blur effect as more pixels are averaged. On completion of the blur process the “unsharp-mask” is subtracted from the original image leaving those areas considered to be fluorosis. The second analytical technique consisted of a convex hull algorithm originally designed to quantify stain on teeth (Taylor, Ellwood et al. 2009). The hypothesis was as the software was designed to detect diffuse areas on the tooth surface it may be able to detect and quantify the diffuse areas of hypomineralization associated with fluorosis.

When subjects without suitable photographic and QLF images were removed from the analysis, data from 553 subjects were available. The ability to detect differences in fluorosis severity at different exposures to fluoride was performed by non-parametric analysis using Mann-Whitney U Test with a simple Bonferroni correction for multiple comparisons. Overall, the convex hull software appeared to be almost as sensitive as the photographic score at discriminating between the water intervals when correcting for multiple pair-wise comparisons. The blur technique appeared to perform less well at lower water fluoride levels. Both software techniques and the photographic scores performed less well for comparisons between water intervals “0.20-0.59ppmF” and “0.60-0.89ppmF” and between water intervals “0.60-0.89ppmF” and “0.90-1.59ppmF”. The cooking water interval “<0.20ppmF” could be seen to represent non-fluoridated populations with perhaps some background fluoride in water. Intervals “0.20-0.59ppmF” and “0.60-0.89ppmF” are commensurate with sub-optimal and optimally fluoridated populations with interval “1.6+ppmF” representing fluoride levels above optimal levels. It would be desirable that any system would be able to discriminate between each of the intervals. However, it could be argued at the levels set in this study the difference between the three lowest intervals is minimal. However, a robust system should be able to discriminate between the highest and the remaining intervals.

Both software analysis techniques demonstrated significant correlations with photographic scores. The metrics for area effected by fluorosis and the fluorescence loss had the strongest association with the photographic TF score (Spearman’s rho 0.664 and 0.652 respectively). Both software techniques performed well for comparison of repeat fluorescence images with ICC values of 0.95 and 0.85 respectively.

The project in Thailand raised important issues during planning and implementation. The efforts of the ICOH to reduce fluoride levels in drinking water and to educate the population on the risks associated with the consumption of excessive fluoride have been successful when considering drinking water supplies. However, issues surrounding sustainability of defluoridation schemes and the continued use of high fluoride groundwater for food preparation and cooking may not address the problem of endemic fluorosis and were a major factor in driving the analysis towards the use of data from cooking water samples. Another factor to address is the staple diet of this population. The consumption of rice is ubiquitous from an early age and it has been shown that rice and cereals have the ability to retain significant quantities of fluoride during cultivation and the soaking process undertaken prior to cooking (Takeda and Takizawa 2008). Therefore, the consumption of rice may be a significant risk factor for dental fluorosis.

The study supported the development of fluorescence imaging for the objective quantification of dental fluorosis. Fluorescence imaging using QLF and a convex hull algorithm was able to demonstrate discrimination between populations with different fluoride exposures and a wide range of fluorosis severity with similar sensitivity to blind scoring of standardized photographic images. However, this study also demonstrated potential limitations of the technology particularly confounding factors during fluorosis detection such as caries and non-fluorotic opacities.

Newcastle Manchester Project

The project in Newcastle was carried out in collaboration with Newcastle University School of Dental Sciences and Newcastle Primary Care Trust. The aims of this project were to determine the effect of social deprivation on the prevalence of caries (including caries lesions restricted to enamel) and enamel fluorosis (on the maxillary central incisors) in areas served by either fluoridated or non-fluoridated drinking water. The study also aimed to explore the use of remote, blinded methodologies to minimize the effect of examiner bias using clinical scoring and remote blinded photographic scoring employing ICDAS criteria for caries and QLF fluorescence imaging for fluorosis. An additional aim was to evaluate subject perception of dental aesthetics, particularly fluorosis.

State secondary schools were approached based upon their willingness to participate and the %FSME of the pupils. Subjects were male and female lifetime residents aged 11-13 years. Consented subjects were asked to confirm lifetime residency in their locality as well as postcode data (to provide individual level deprivation status based on the IMD) before being asked to complete two short computer based questionnaires. The first, on oral hygiene practices exploring brushing and rinsing habits. The second, on tooth aesthetics ranking in order of preference 10 images comprising various presentations of teeth including white teeth, a spectrum of developmental defects of enamel and dental caries.

Clinical assessments of caries and fluorosis were performed on permanent teeth using ICDAS criteria to generate DMFT data and blind scoring of standardized photographs of maxillary central incisors using TF Index. Intra-oral images were taken for remote blind scoring for caries and fluorescence images using QLF were taken of the maxillary central incisors in order to quantify fluorosis. Subjects were given instructions to complete a three day diet diary and a randomly selected cohort were requested to return to have a structured interview with a dietician to explore the frequency of consumption of NMES.

Data was available from the clinical examinations for 1783 subjects (910 Newcastle, 873 Manchester). Levels of material deprivation (IMD) obtained from postcode data were comparable for both populations (Newcastle mean 35.22, range 2.77-78.85; Manchester mean 37.04, range 1.84-84.02).

Consented subjects were invited to rank in order of preference (appearance) a collage of 10 images on a touch-screen laptop. The photographs comprised an assortment of presentations of teeth that included white teeth, a spectrum of developmental defects of enamel and dental caries. Data were captured directly and exported into SPSS for analysis. Data were available for 1553 subjects. In general, there were no significant differences in the rank positions between the two cities, with the exception of teeth with caries and teeth with large demarcated opacities. There was a trend for teeth with fluorosis to be more tolerated in the fluoridated community. The results of this study suggest teeth that are either very white have the highest preference but teeth with a fluorosis score of TF 1 may not be deemed unattractive to this population and age group. Images depicting teeth with caries or large demarcated opacities were deemed to be the least favoured. Subject preference of images depicting fluorosis fell with increasing severity of fluorosis.

The results from the oral hygiene practices questionnaire (n=871 Manchester, n=891 Newcastle) revealed no significant differences between the two populations for the size of toothbrush head and quantity of dentifrice used (Mann Whitney U $p>0.05$). However, there were significant differences between the localities relating to rinsing habits for subjects who reported not rinsing after brushing where 16% of subjects in Manchester reported not rinsing after brushing compared to only 9% in Newcastle (chi squared test $p<0.001$). In both populations approximately 40% of subjects reported rinsing with a glass or beaker.

128 subjects undertook the dietary interview (n=63 Manchester, n=65 Newcastle). The cohort data suggested that between the two study areas there were no significant differences either in terms of frequency of NMES intake (Mann Whitney U test p=0.776) or NMES consumed in the last hour before bedtime(Mann Whitney U test p=0.874).

Subjects in the fluoridated population in Newcastle had significantly less caries experience than the non-fluoridated Manchester population for early caries white spot lesions and caries into dentine ($p<0.0001$). The mean D_{1-6}MFT in Newcastle was 2.94 (clinical); 2.51 (photo) and for Manchester 4.48 (clinical); 3.44 (photo). For visible caries into dentine the mean D_{4-6}MFT in Newcastle was 0.65 (clinical); 0.58 (photo) and for Manchester the mean D_{4-6}MFT was 1.07 (clinical); 0.98 (photo). This was reflected as an increase in caries as the level of deprivation increased, the only exception being for the least deprived quintile for caries into dentine where there were no significant differences between the cities. The Odds Ratio for white spot caries experience (or worse) in Manchester was 1.9 relative to Newcastle. The Odds Ratio for caries into dentine in Manchester was 1.8 relative to Newcastle. The Odds Ratio for developing fluorosis in Newcastle was 3.3 relative to Manchester.

The results from the intra-oral images were in general agreement with the results from the clinical scoring. However, whilst the direction of differences in caries levels found between the fluoridated and non-fluoridated populations was the same, the data derived from the intra-oral images was consistently lower than the clinical data. This appeared to be owing to specula reflection confounding scoring and, more critically, images not permitting adequate visualization of interproximal areas on posterior teeth. However, there was very good agreement between the clinical scores and photographic scores for first molar occlusal surfaces (weighted Kappa 0.83) and both clinical and remote photographic scoring techniques were able to discriminate between the populations.

Logistic regression models with the effect of fluoridation status, age at exam and deprivation as explanatory variables with the presence or absence of caries into dentine as the outcome variable produced similar Odds Ratios to the raw Odds Ratios. All three explanatory variables were statistically significant. The Odds Ratio for developing caries of 1.840 (95% CI 1.500, 2.258) for children in Manchester compared to Newcastle (assuming other explanatory variables held constant). The model also demonstrated increasing Odds Ratios for caries with each increase in quintile of deprivation and an Odds Ratio of 1.347 (95% CI 1.123, 1.616) for developing caries in to dentine with each additional year of life. The model was shown to have very good predictive value.

The logistic regression model for caries at a white spot lesion threshold provided an Odds ratio of 2.11 (95% CI 1.622, 2.680) for children in Manchester compared to Newcastle. Once again, Odds Ratios increased as quintile of deprivation increased as did the Odds Ratio for age at exam. However, the predictive value for this model was lower than the model for caries into dentine.

1775 subjects had satisfactory photographic information (906 Newcastle; 869 Manchester). The prevalence of fluorosis in fluoridated Newcastle was 55%, in non-fluoridated Manchester it was 27%. In Newcastle, 48% of subjects had TF scores of 1 or 2 and 7.1% of subjects had TF scores of 3 or greater. In Manchester the corresponding values were 26% and 1.2% respectively. Repeat scoring of photographic images were available for 98 subjects and demonstrated very good agreement (weighted Kappa =0.75).

Subjects in Newcastle were found to be 3.3 times more likely to have fluorosis than subjects in Manchester ($p<0.001$). when the severity of fluorosis was thresholded at TF 3 or higher this rose to 10.5 times more likely in Newcastle compared to Manchester ($p<0.001$).

A logistic regression model with fluoridation status and quintile of IMD as explanatory variables with the presence or absence of fluorosis as the dependent variable generated an Odds Ratio of 3.390 (95% CI 2.780, 4.152) in Newcastle when compared to Manchester. The effect of deprivation on fluorosis was only significant for subjects in the least deprived quintile of IMD. The Odds Ratio of developing fluorosis was 1.508 (95% CI 1.101, 2.065) for those in the least deprived quintile of IMD when compared to the most deprived quintile. This model had a reasonable predictive value.

Data were available for 1774 subjects (n=905 Newcastle, n=869 Manchester) for QLF analysis. The QLF metric ΔQ_{ch} increased as the fluorosis severity increased. Intra Class Correlation Coefficients demonstrated a significant correlation with TF Index scores from photographs (Kendall's tau = 0.0.332 p<0.0001). However, a number of additional confounding factors such as the presence of extrinsic stain or increased enamel translucency on some subjects without fluorosis or at low levels of fluorosis severity had an adverse impact on tooth fluorescence and hence the outcome variable. This in conjunction with an uneven distribution of subjects across the range of fluorosis presentations may have resulted in the lower than anticipated correlations between the fluorescence imaging metrics and the photographic fluorosis scores.

The project in Newcastle and Manchester required engagement with another academic institution, Primary care trusts, local authorities and the participating schools. The logistic effort involved in conducting a large scale study of this nature highlighted a number of issues. As well as the planning and implementation of the study, the consent process required the engagement of parents and positive consent from the subjects. Changes in legislation and attitudes no longer permitted the use of negative consent for observational epidemiological surveys which impacted on recruitment rates. It is difficult to determine if this influenced the outcome of the study.

The results from the study support the hypothesis that water fluoridation reduces dental caries. The assumption that subjects used fluoridated dentifrice and efforts to address confounding factors such as age at examination, diet, oral hygiene practices and deprivation would support the hypothesis that water fluoridation in Newcastle provides an additional benefit for caries prevention. The data exploring the effect of deprivation on caries supported the hypothesis that caries levels increase as deprivation increases creating an inequality in oral health. Water fluoridation may continue to address inequalities in oral health by reducing the social class gradient between deprivation and caries experience. However, this may associated with an increased risk of developing fluorosis.

The decision to use ICDAS criteria to generate DMFT data would appear to have delivered a more sensitive and adaptable means of caries assessment with negligible detrimental effects on examination time. It was hoped the use of remote scoring of intra-oral images for caries would facilitate efforts to reduce examiner bias and this was met with a measure of success but the effects of specula reflection and the potential loss of interproximal information requires additional thought if the methodology is to be developed further.

The overall prevalence of fluorosis in Newcastle does not seem to have increased in the ten year period since the work of Tabari and Ellwood et al (Tabari, Ellwood et al. 2000) but there may be an increase in the prevalence of aesthetically significant fluorosis. However, it is difficult to determine if this is a true increase or a result of examiner thresholding or image viewing medium.

The development of QLF as a system for quantifying fluorosis has been a partial success. The limitations of the technology with respect to confounding factors creates difficulties for employing QLF as a diagnostic system and the lack of an appropriate gold standard not only creates difficulties with statistical analysis but also any assessment of sensitivity and specificity is problematic. The decision to continue with the QLF system in the study was based on the encouraging associations with TF Index scores from earlier work Despite these limitations the fluorescence imaging system may yet provide a useful objective, blinded system for the assessment of enamel fluorosis when used adjunctively with photographic scoring. The ability of QLF to provide reliable continuous data may facilitate the longitudinal assessment of fluorosis.

It was not possible, nor was it the intention, for this thesis to address all of the issues and potential confounding factors highlighted in the York Report. Nevertheless, it should be stated there has been success in the development of methodologies to improve the evidence base, many of which were incorporated into an epidemiological survey. A summary of the issues raised and the means by which they were addressed by the project are described in Table 10.2. The most difficult aspects to address were total fluoride intake and the consumption of dietary sugars. The recording of fluoride intake in this study could have resulted in recall bias and as a consequence (with the exception of recording a history of fluoride supplement use) the total fluoride intake from sources other than community water supplies was assumed to be the same in both populations. The recording of dietary sugar consumption required the use of interviews and food diaries. In an epidemiological survey for dental caries this becomes both time-consuming and expensive when considering large populations. This highlighted the need to develop assessment tools that are quick and reliable to use in such surveys whilst providing data on an individual level.

The work in this thesis has evaluated methods that may be adopted in future studies to assess caries and fluorosis. It is clear some of the techniques require additional development and validation, particularly QLF in the detection of fluorosis.

Table 10.2. Summary table of research recommendations from York Report and MRC and how thesis has attempted to address them.

Recommendations for Future Research from York and MRC	Method of Addressing Issues (Chapter of thesis)	Conclusions
Caries		
Observer bias-examiner blinding	Intra-oral photography with remote blind scoring (Chapter 8)	Quality of images requires improvement but demonstrates potential as a reliable means of reducing bias with the ability to discriminate between fluoridated and non-fluoridated populations
Method/standardization of assessment	Use of ICDAS index to attempt to improve sensitivity and structure of caries assessment (Chapter 8)	ICDAS can be time consuming and requires thorough drying of teeth but demonstrated the ability to report caries at lower severity levels, an important factor to consider when reporting disease trends
Frequency of sugar consumption	Use of diet dairies and structured interview for cohort group (Chapter 8)	The use of the cohort provided a basic level of investigation for the populations. Further work is needed to develop tools to evaluate sugar consumption at an individual level in a practical and meaningful manner for epidemiological surveys.
Total fluoride Intake	Historical recording impractical and unreliable. Fluoride intake from sources other than community water supply were assumed to be identical for the purposes of the project	Not logistically possible to attempt in project of this nature but remains an important factor for consideration in establishing fluorosis risk
Knowledge of the effect of water fluoridation by social class on caries	Use of %FSME to target schools with balance between cities and range of deprivation. Use of IMD from patient postcode to provide individual level data. (Chapter 8)	The project has demonstrated there are simple and reliable means of recruiting subjects with a range of deprivation in studies and providing individual level data
Fluorosis		
Observer bias-examiner blinding	Remote blinded scoring of standardized photographs/QLF imaging for objective quantification (Chapters 8 and 9).	Remote scoring of standardized photographs is an accepted means of reducing bias. QLF has demonstrated the ability to quantify fluorosis but limitations to technique rely upon a clinical diagnosis prior to quantification.
Cross-sectional studies to determine current prevalence	Cross-sectional survey in selected fluoridated and non-fluoridated populations with a range of deprivation (Chapters 8 and 9).	The project demonstrated a current picture of fluorosis prevalence and severity in adolescents. Data on other age groups over a period of time are needed to evaluate trends in prevalence and severity
Public's perception of fluorosis	Subject assessment of tooth aesthetics including a range of fluorosis presentations (Chapter 7).	The project provided an indication of this population's perception of tooth aesthetics including fluorosis

Recommendations for future research

1) The difficulties in gaining access to the study population and the associated effects on consent for epidemiological surveys warrant research to evaluate engagement processes between key stakeholders and novel, adaptable methods to address falling participation rates. This is essential to retain the validity of research moving forward.

2) There remains a need to fully investigate the effect of water fluoridation on caries through the evaluation of existing and new fluoridation schemes. This will require substantial investment over a prolonged period. Study designs would require serial cross sectional surveys employing methodologies such as conventional and fluorescence imaging as well as the prospective monitoring of birth cohorts to include anthropometric factors and total fluoride ingestion during the period of amelogenesis to assess fluorosis risk. The evaluation of sugar consumption in individuals would be needed to assess caries risk requiring the development of assessment tools.

3) Caries assessment using ICDAS criteria requires further work together with direct comparison to BASCD criteria within the same population. The use of ICDAS may provide more flexibility in reporting caries prevalence in populations and facilitate the evaluation of caries prevention strategies and interventions.

4) The use of intra-oral cameras to facilitate remote blinded scoring for dental caries requires additional work and validation. The quality of images may be improved through the use of polarizing filters to reduce specula reflection. Techniques should be explored to address difficulties associated with scoring the interproximal areas of the teeth using photographic images in order to prevent loss of information.

5) The software employed in QLF analysis has opportunities for further development. Edge detection techniques may facilitate more rapid production of masks for teeth. Software applications may enable more accurate mapping of opacities of differing aetiology on the tooth surface to reduce confounding factors during fluorosis quantification.

6) The techniques developed through the evolution of the QLF system may inform the development of similar systems for caries and fluorosis detection using novel imaging

techniques such as near infra red. Work on dual camera systems with polarized white light and QLF derived images is currently underway.

References

MRC (2002). Medical Research Council Working Group Report. Water fluoridation and health. London, MRC.

NHS-CRD (2000). A Systematic Review of Public Water Fluoridation. York, The University of York, NHS Centre for Reviews and Dissemination (Report 18).

Pretty, I. A., J. A. Tavener, et al. (2006). "Quantification of dental fluorosis using fluorescence imaging." Caries Res **40**(5): 426-34.

Tabari, E. D., R. Ellwood, et al. (2000). "Dental fluorosis in permanent incisor teeth in relation to water fluoridation, social deprivation and toothpaste use in infancy." Br Dent J **189**(4): 216-20.

Takeda, T. and S. Takizawa (2008). Health Risks of Fluoride in the Chiang Mai Basin, Thailand. Groundwater Management in Asian Cities. Technology and Policy for Sustainability. S. Takizawa. Tokyo, Springer**:** pp301-327.

Taylor, A. M., R. P. Ellwood, et al. (2009). "Quantitative stain detection in vivo using fluorescent imaging." J Dent **37**(5): 397-405.

van der Veen, M. H. and E. de Josselin de Jong (2000). "Application of quantitative light-induced fluorescence for assessing early caries lesions." Monogr Oral Sci **17**: 144-62.

Further Studies in Caries and Fluorosis

Appendices

APPENDIX 1: ICDAS CRITERIA

ICDAS Coronal Primary Caries Detection Criteria

Coronal Primary Caries Codes

Sound tooth surface: Code 0

There should be no evidence of caries (either no or questionable change in enamel translucency after prolonged air drying (suggested drying time 5 seconds)). Surfaces with developmental defects such as enamel hypoplasias; fluorosis; tooth wear (attrition, abrasion and erosion), and extrinsic or intrinsic stains will be recorded as sound. The examiner should also score as sound a surface with multiple stained fissures if such condition is seen in other pits and fissures, a condition which is consistent with non-carious habits (e.g. frequent tea drinking).

First visual change in enamel: Code 1

Code 1 is assigned for the following pits and fissures.

When seen wet there is no evidence of any change in colour attributable to carious activity, but after prolonged air drying (approximately 5 seconds is suggested to adequately dehydrate a carious lesion in enamel) a carious opacity or discolouration (white or brown lesion) is visible that is not consistent with the clinical appearance of sound enamel.

OR

When there is a change of colour due to caries which is not consistent with the clinical appearance of sound enamel and is limited to the confines of the pit and fissure area (whether seen wet or dry). The appearance of these carious areas is not consistent with that of stained pits and fissures as defined in code 0.

Distinct visual change in enamel: Code 2

The tooth must be viewed wet. When wet there is a (a) carious opacity (white spot lesion) and/or (b) brown carious discolouration which is wider than the natural fissure/fossa that is not consistent with the clinical appearance of sound enamel (Note: the lesion must still be visible when dry).

Localized enamel breakdown with no visible dentine or underlying shadow: Code 3

The tooth viewed wet may have a clear **carious opacity (white spot lesion) and/or brown carious discolouration which is wider than the natural fissure/fossa that is not consistent with the clinical appearance of sound enamel.** Once dried for approximately 5 seconds there is carious loss of tooth structure at the entrance to, or within, the pit or fissure/fossa. This will be seen visually as evidence of demineralization (opaque (white), brown or dark brown walls) at the entrance to or within the fissure or pit, and although the pit or fissure may appear substantially and unnaturally wider than normal, the dentine is NOT visible in the walls or base of the cavity/discontinuity.

If in doubt, or to confirm the visual assessment, a WHO/CPI/PSR probe can be used **gently across a tooth surface** to confirm the presence of a cavity apparently confined to the enamel. This is achieved by sliding the ball end along the suspect pit or fissure and a limited discontinuity is detected if the ball drops into the surface of the enamel cavity/discontinuity.

Underlying dark shadow from dentine with or without localized enamel breakdown: Code 4

This lesion appears as a shadow of discoloured dentine visible through an apparently intact enamel surface which may or may not show signs of localized breakdown (loss of continuity of the surface that is not showing the dentine). The shadow appearance is often seen more easily when the tooth is wet. The darkened area is an intrinsic shadow which may appear as grey, blue or brown in colour. The shadow must clearly represent caries that started on the tooth surface being evaluated. If in the opinion of the examiner, the carious lesion started on an adjacent surface and there no evidence of any caries on the surface being scored then the surface should be coded “0”.

Code 3 and 4, histologically may vary in depth with one being deeper than the other and vice versa. This will depend on the population and properties of the enamel. For example more translucent and thinner enamel in primary teeth may allow the undermining discolouration of the dentine to be seen before localized breakdown of enamel. However, in most cases code 4 is likely to be deeper into dentine than code 3.

Distinct cavity with visible dentine: Code 5
Cavitation in opaque or discoloured enamel exposing the dentine beneath.

The tooth viewed wet may have darkening of the dentine visible through the enamel. Once dried for 5 seconds there is visual evidence of loss of tooth structure at the entrance to or within the pit or fissure – frank cavitation. There is visual evidence of demineralization (opaque (white), brown or dark brown walls) at the entrance to or within the pit or fissure and in the examiner's judgment dentine is exposed.

A WHO/CPI/PSR probe can be used to confirm the presence of a cavity apparently in dentine. This is achieved by sliding the ball end along the suspect pit or fissure and a dentine cavity is detected if the ball enters the opening of the cavity and in the opinion of the examiner the base is in dentine. (In pits or fissures the thickness of the enamel is between 0.5 and 1.0 mm. Note the deep pulpal dentine should not be probed).

Extensive distinct cavity with visible dentine: Code 6
Obvious loss of tooth structure, the cavity is both deep and wide and dentine is clearly visible on the walls and at the base. An extensive cavity involves at least half of a tooth surface or possibly reaching the pulp.

Smooth surface (mesial and distal)

This requires visual inspection from the occlusal, buccal and lingual directions.

Sound tooth surface: Code 0
There should be no evidence of caries (either no or questionable change in enamel translucency after prolonged air drying (suggested drying time 5 seconds)). Surfaces with

developmental defects such as enamel hypoplasia; fluorosis; tooth wear (attrition, abrasion and erosion), and extrinsic or intrinsic stains will be recorded as **sound**.

First visual change in enamel: Code 1

When seen wet there is no evidence of any change in colour attributable to carious activity, but after prolonged air drying a carious opacity (white or brown lesion) is visible that is not consistent with the clinical appearance of sound enamel. This will be seen from the buccal or lingual surface.

Distinct visual change in enamel when viewed wet: Code 2

There is a carious opacity or discolouration (white or brown lesion) that is not consistent with the clinical appearance of sound enamel (Note: the lesion is still visible when dry). This lesion may be seen directly when viewed from the buccal or lingual direction. In addition, when viewed from the occlusal direction, this opacity or discolouration may be seen as a shadow confined to enamel, seen through the marginal ridge.

Initial breakdown in enamel due to caries with no visible dentine: Code 3

Once dried for approximately 5 seconds there is distinct loss of enamel integrity, viewed from the buccal or lingual direction.

If in doubt, or to confirm the visual assessment, the CPI probe can be used gently across the surface to confirm the loss of surface integrity.

Underlying dark shadow from dentine with or without localized enamel breakdown: Code 4

This lesion appears as a shadow of discoloured dentine visible through the enamel surface beyond the white or brown spot lesion, which may or may not show signs of localized breakdown. This appearance is often seen more easily when the tooth is wet and is a darkening and intrinsic shadow which may be grey, blue or brown in colour.

This lesion appears as a shadow of discoloured dentine visible through an apparently intact marginal ridge, buccal or lingual walls of enamel. This appearance is often seen more easily when the tooth is wet. The darkened area is an intrinsic shadow which may appear as grey, blue or brown in colour.

Distinct cavity with visible dentine: Code 5.

Cavitation in opaque or discoloured enamel (white or brown) with exposed dentine in the examiner's judgment.

If in doubt, or to confirm the visual assessment, the CPI probe can be used to confirm the presence of a cavity apparently in dentine. This is achieved by sliding the ball end along the surface and a dentine cavity is detected if the ball enters the opening of the cavity and in the opinion of the examiner the base is in dentine.

Extensive distinct cavity with visible dentine: Code 6

Obvious loss of tooth structure, the extensive cavity may be deep or wide and dentine is **clearly visible** on both the walls and at the base. The marginal ridge may or may not be present. An extensive cavity involves at least half of a tooth surface or possibly reaching the pulp.

<u>Free Smooth surface (buccal and lingual and direct examination of mesial and distal surfaces (with no adjacent teeth)</u>

Sound tooth surface: Code 0

There should be no evidence of caries (either no or questionable change in enamel translucency after prolonged air drying (approximately 5 seconds)). Surfaces with developmental defects such as enamel hypoplasias; fluorosis; tooth wear (attrition, abrasion and erosion), and extrinsic or intrinsic stains will be recorded as sound.

First visual change in enamel: Code 1

When seen wet there is no evidence of any change in colour attributable to carious activity, but after prolonged air drying a carious opacity is visible that is not consistent with the clinical appearance of sound enamel.

Distinct visual change in enamel when viewed wet: Code 2

There is a carious opacity or discolouration that is not consistent with the clinical appearance of sound enamel (Note: the lesion is still visible when dry). The lesion is located in close proximity (in touch or within 1 mm) of the gingival margin

Localized enamel breakdown due to caries with no visible dentine: Code 3

Once dried for 5 seconds there is carious loss of surface integrity without visible dentine.

If in doubt, or to confirm the visual assessment, the CPI probe can be used with NO digital pressure to confirm the loss of surface integrity.

Underlying dark shadow from dentine with or without localized enamel breakdown: Code 4

This lesion appears as a shadow of discoloured dentine visible through the enamel surface beyond the white or brown spot lesion, which may or may not show signs of localized breakdown. This appearance is often seen more easily when the tooth is wet and is a darkening and intrinsic shadow which may be grey, blue or brown in colour.

Distinct cavity with visible dentine: Code 5

Cavitation in opaque or discoloured enamel exposing the dentine beneath.

If in doubt, or to confirm the visual assessment, the CPI probe can be used with NO digital pressure to confirm the presence of a cavity apparently in dentine. This is achieved by sliding the ball end along the surface and a dentine cavity is detected if the ball enters the opening of the cavity and in the opinion of the examiner the base is in dentine.

Extensive distinct cavity with visible dentine: Code 6

Obvious loss of tooth structure, the cavity is both deep and wide and dentine is clearly visible on the walls and at the base. An extensive cavity involves at least half of a tooth surface or possibly reaching the pulp.

APPENDIX 2: THAILAND INFORMATION SHEETS AND CONSENT FORMS (ENGLISH TRANSLATIONS)

MANCHESTER 1824

The University of Manchester

The Dental Health Unit
3A Skelton House
Manchester Science Park
Lloyd Street North, Manchester
M15 6SH

Dr Iain A Pretty

Tel: 0161 226 1211
Fax: 0161 232 4700

Oral Health Care Study – Parent's Information Sheet

Dear Parent or Guardian

I am writing to you to ask for your consent (agreement) for your child to be involved in a clinical research study that we are conducting in conjunction with the University of Chiang Mai and the Department of Health. Before you can agree for your child to take part, I would like to give you some more information about the background to the study. I also suggest that you read the information provided to your child to ensure you are happy that it reflects what we aim to do.

Dental Decay and Fluorosis

Dental caries, or decay, is still a major problem within the United Kingdom (UK) and in Thailand. A number of measures have reduced the amount of decay within certain parts of the population and the most important of these are fluoride in both water supplies and toothpaste. Dental decay often requires a visit to the dentist and the placement of a filling. This will often mean time off school and work for both child and parent. Untreated dental decay can lead to painful toothache which may ultimately require a tooth to be extracted. Sometimes there can be too much fluoride naturally present in the water. A minor side effect of too much fluoride is the appearance of white patches on the teeth – fluorosis. We wish to measure the amount of fluorosis present on teeth in areas with different concentrations of fluoride in the drinking water. This study may help identify areas with too much fluoride in the water in Chiang Mai and may to help decide if some should be removed – this is called defluoridation.

Water fluoridation

Many areas of the UK still do not benefit from water fluoridation. Recent changes in the law in the UK will enable more local governments to implement water fluoridation if they choose. However, in order for this to take place we will need to have improved methods of assessing the value of adding fluoride to the water. Our research group is interested in developing new ways of looking at fluorosis that will help in evaluating new water fluoridation programmes.

Why is my child being asked to participate?

We are running this study in Chiang Mai because there are areas with different amounts of fluoride in the drinking water. By looking at these different areas we will be able to see the differences that water fluoridation makes to the oral health of the children living in these regions. We cannot do this study in the UK because there are not enough areas that contain the different levels of fluoride in the water that are present in Chiang Mai. Your child has not been individually selected – we are asking the parents or guardians of all children aged 8 – 12 in this school if they would like to participate. Your child will be part of a group of approximately 600 we aim to assess. Participation in this study is entirely voluntary. You or your child may choose to withdraw from the study at any time and you do not have to give us a reason.

What will happen to my child if they participate in the study?
If you, and your child, agree to take part in the study they will be contacted at school. We will do a number of different examinations. The first will be a very standard dental check up where a dentist will look at your child's teeth. Next, a few pictures will be taken. The first group of these pictures will be done with a special camera using blue light looking only at the front teeth. Then some more pictures will be taken with a standard camera. It will be necessary to dry the teeth using some compressed air, just like at a regular dentist's surgery. None of the photographs will show your child's face – they will only be of their teeth. We would expect that all of the examinations will take no more than 30 minutes. All of the examinations are done without any probing of the teeth; just with either a mirror or a camera and are completely painless. At any stage your child can decide that they do not want to continue with the study. After the examinations are done your child will be asked to complete a very simple survey on how the white patches on their teeth (if any) affect their daily activities. After this your child will go back to their classroom. We will look at the images we have taken after the study has finished.

The results of this study may help us to identify children who may be suitable for future studies, if your child is suitable we may contact you again. You and your child would not be under any obligation to take part in any future studies.

Where will all these photographs be kept and who has access to them?
We will store all the photographs and clinical information on computers that are secured with a password. None of the information that we collect will be linked to your child, i.e. the information will be anonymous. The only people to have access to the information are the scientists involved in the study. We hope to publish our results in a scientific journal. No information concerning your child will be included. We will provide a copy of the results to your child's school if you would like to see them. The study may be monitored by external bodies such as the ethics committee or regulatory authorities. Once again, your child will not be identified during this process.

What if my child has something wrong with their teeth?
If the examining dentist notices something in your child's mouth that they feel needs treating they will write to you and let you know. You can take this letter to a dentist and they will be able to advise you further.

What benefit is there to me or my child?
This study aims to understand better the link between the amount of fluorosis present on teeth and the level of fluoride in drinking water. You and your child will be helping us to develop more information on this important issue. Your child may not gain a direct benefit by taking part in this study but they will receive a full dental examination and this may help identify any problems that they have. Once your child has finished they will be given a small gift to thank them for their help.

What risks are there to my child taking part?
There are no risks to your child taking part in this study. All of the procedures and equipment being used have a safe history of use and have been used in studies before. In the unlikely

event that something does go wrong and your child is harmed during the research and this is due to someone's negligence then you may have grounds for a legal action for compensation.

Who is paying for this study?

The University of Manchester is the study sponsor and the funding is sourced from the Department of Health in the United Kingdom. Further support for this study is being provided by the University of Chiang Mai.

Who has reviewed this study?

This research has been looked at by an independent group of people called a research ethics committee to protect the safety, wellbeing, rights and dignity This study has been reviewed and given a favourable opinion by the University of Manchester Committee on the Ethics of Research on Human Beings.of you and your child. This study has been reviewed and given a favourable opinion by the University of Manchester Committee on the Ethics of Research on Human Beings.

Who is running this study, what if I have a question?

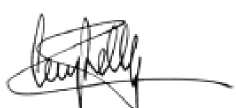
The study is being undertaken by researchers at the Universities of Manchester and Chiang Mai. In Manchester Dr Iain Pretty is the principle investigator, and in Chiang Mai, Assoc. Prof. Patcharawan Srisilapanan is leading the team. You will find their contact details at the end of this letter. If you have any questions regarding the study please feel free to contact Mike McGrady. You can contact him by email (michael.mcgrady@manchester.ac.uk).

What do I do now?

Please complete the consent form that is attached to this letter. This is very important, even if you do not wish your child to take part. It would be very helpful to us if you could send the form back to your school.

I would like to thank you for reading this information sheet and considering your child's inclusion in the study.

Yours Sincerely



Dr Iain Pretty

Address Details

Dr Iain A Pretty
Senior Lecturer
School of Dentistry
University of Manchester
Skelton House
Manchester, M15 6SH

Assoc. Prof. Patcharawan Srisilapanan
Faculty of Dentistry
Chiang Mai University
Chiang Mai
50200
Thailand

Michael McGrady
Senior Research Fellow
School of Dentistry
University of Manchester
Skelton House
Manchester, M15 6SH

MANCHESTER 1824

The University of Manchester

The Dental Health Unit
3A Skelton House
Manchester Science Park
Lloyd Street North, Manchester
M15 6SH

Dr Iain A Pretty

Tel: 0161 226 1211
Fax: 0161 232 4700

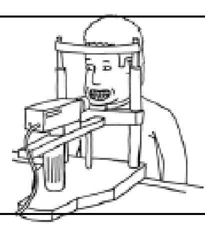
Oral Health Care Study – Child's Information Sheet

Dear Student

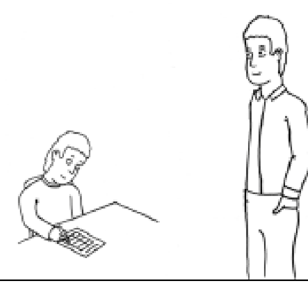
I am writing to ask you if you would like to take part in a research project (study) that I and some scientists from Chiang Mai University are running in your area. I have also written to your parents or guardian. The first thing we will do is to make sure your parents have said it is ok for you to take part.

We would like you to help us look at white patches on teeth in school children about your age. We will look at 600 children around the Chiang Mai area

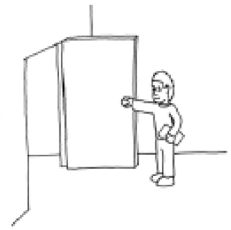
We will look in your mouth like a normal check-up at the dentist. We will look to see if there are white patches on your teeth



We will take pictures of your front teeth. These pictures will be of only your front teeth using a special camera with a frame to hold your head in the right place. After that we will use an ordinary camera to take pictures of your front teeth



We will then ask you a few questions and fill in a simple form



When you have finished your questions you can go back to class. We will give you a small gift to say thank you for helping us.

If you have any questions please ask us, if you do not want to take part, you do not have to. It is up to you!

Thanks again!

Iain Pretty

Address Details

Dr Iain A Pretty
Senior Lecturer
School of Dentistry
University of Manchester
Skelton House
Manchester, M15 6SH

Assoc. Prof. Patcharawan Srisilapanan
Faculty of Dentistry
Chiang Mai University
Chiang Mai
50200
Thailand

Michael McGrady
Senior Research Fellow
School of Dentistry
University of Manchester
Skelton House
Manchester, M15 6SH

MANCHESTER 1824
The University of Manchester

Oral Health Care Study

CONSENT FORM

Adhesive label to contain the following information; Initials, Class, School & ID	Signature of Investigator once consent obtained: ______________________ Date:__________

If you **want your child to take part** in this study please tick this box, complete the information in the box below this one, ***sign and date it*** before returning it to your child's class teacher. ☐

If you **do not want your child to take part** in this study please ***sign*** this box and return the form to your child's class teacher. ☐

Contact details

Address

Telephone number (evening)

Telephone number (day)

Has your child always lived at this address or in this neighbourhood? If "yes" please tick the box on the right. ☐
If the answer is "no" how long have they lived in this area? _____ years ______ months

Please tick this box if your child has ever taken fluoride tablets, drops or any other form of fluoride supplement. **If you tick yes please indicate below when, and what fluoride supplements were taken** ☐

Please list any allergies that your child has in the box below e.g. Latex Allergy

I have read the explanation of this study in the accompanying letter with this consent form and I agree that my child can take part in the dental study. I understand that all information collected during the study will be kept confidentially but will be made available to the study Sponsor or Governmental Agencies.

....	....	....	....
Signed by parent	Date	Signed by child (Optional)	Date

Please return this page of this letter to your child's class teacher

APPENDIX 3: NEWCASTLE/MANCHESTER LETTERS, INFORMATION SHEETS AND CONSENT FORMS

MANCHESTER 1824
The University of Manchester

The Dental Health Unit
3A Skelton House
Manchester Science Park
Manchester
M15 6SH

Dr. Iain A Pretty, BDS, MSc, PhD, MFDS RCS(Ed)
Senior Lecturer in Dental Public Health
Postgraduate Research Trainer

Tel: 0161 226 1211
Fax: 0161 232 4700

www.dentalhealthunit.org
iain.pretty@manchester.ac.uk

IP/ms

25-Oct-07

Chair of LDC

Dear Sir or Madam,

Re: Dental study taking place in the North East and North West

I am writing to you to on behalf of a research team based here at the University of Manchester and Newcastle University to tell you about a project that we intend to run within schools in Manchester and Newcastle.

Legislative changes in the UK will shortly enable more areas of the country to assess the feasibility of water fluoridation. Prior to the implementation of such new schemes, one of which may be based in Manchester, it is essential that as dental researchers we can develop better techniques to assess the benefits of such a public health measure. As part of the development of strategies to assess such benefits we are testing some new ways of measuring dental caries. This has the support of the Medical Research Council. We have chosen Newcastle and Manchester as the sites for our study because they contain clearly defined areas of fluoridated and non-fluoridated water supplies.

Children in your area will be asked to participate in a brief dental examination and have a number of photographs taken – all of which will show only their teeth. The study has been approved by the University of Manchester Ethics Committee and all individuals taking part will be provided with information sheets and will sign an informed consent form. I have attached these to this letter for your information.

As part of this examination we are required to inform the child and their parents of any dental treatment that is deemed necessary. In reality this will relate to grossly carious teeth and signs of sepsis. This could result in an increase in attendance of regular child patients or an increase in requests for new patient exams for dentists within your LDC area. I have attached to this letter a copy of the form that will be returned the child's parents.

Do please contact me if you have any further questions.

Kindest regards

IAIN A PRETTY	GILL DAVIES	MICHAEL MCGRADY

Address Details

Dr Iain A Pretty Senior Lecturer School of Dentistry University of Manchester Skelton House Manchester, M15 6SH	Dr Gill Davies Senior Dental Officer Specialist in Dental Public Health Dept Dental Public Health Mauldeth House Mauldeth Road West Manchester, M21 7RL	Mr Michael McGrady Senior Research Fellow School of Dentistry University of Manchester Skelton House Manchester, M15 6SH

MANCHESTER 1824

The University of Manchester

The Dental Health Unit
3A Skelton House
Manchester Science Park
Manchester
M15 6SH

Dr. Iain A Pretty, BDS, MSc, PhD, MFDS RCS(Ed)
Senior Lecturer in Dental Public Health
Postgraduate Research Trainer

Tel: 0161 226 1211
Fax: 0161 232 4700

www.dentalhealthunit.org
iain.pretty@manchester.ac.uk

IP/ms

25-Oct-07

Head of LEA

Dear Sir or Madam,

Re: Dental study taking place in the North East and North West

I am writing to you to on behalf of a research team based here at the University of Manchester and Newcastle University to tell you about a project that we intend to run within schools in Newcastle and Manchester.

Legislative changes in the UK will shortly enable more areas of the country to assess the feasibility of water fluoridation. Prior to the implementation of such new schemes, one of which may be based in Manchester, it is essential that as dental researchers we can develop better techniques to assess the benefits of such a public health measure. As part of the development of strategies to assess such benefits we are testing some new ways of measuring dental caries. This has the support of the Medical Research Council. We have chosen Newcastle and Manchester as the sites for our study because they contain clearly defined areas of fluoridated and non-fluoridated water supplies.

One or more schools within your LEA will be invited to participate and the approval of the Head Teach will be sought. Children will be asked to participate in a brief dental examination and have a number of photographs taken – all of which will show only their teeth. The study has been approved by the University of Manchester Ethics Committee and all individuals taking part will be provided with information sheets and will sign an informed consent form. I have attached these to this letter for your information.

I do hope that this provides you with sufficient information. However, if you would like sight of the full protocol, or if you have any further questions please do not hesitate to contact to me at the address above.

Kindest regards

IAIN A PRETTY **GILL DAVIES** **MICHAEL MCGRADY**

Address Details

Dr Iain A Pretty
Senior Lecturer
School of Dentistry
University of Manchester
Skelton House
Manchester, M15 6SH

Dr Gill Davies
Senior Dental Officer
Specialist in Dental Public Health
Dept Dental Public Health
Mauldeth House
Mauldeth Road West
Manchester, M21 7RL

Mr Michael McGrady
Senior Research Fellow
School of Dentistry
University of Manchester
Skelton House
Manchester, M15 6SH

MANCHESTER 1824

The University of Manchester

3A Skelton House
Manchester Science Park
Manchester
M15 6SH

Dr. Iain A Pretty, BDS, MSc, PhD, MFDS RCS(Ed)
Senior Lecturer in Dental Public Health
Postgraduate Research Trainer

Tel: 0161 226 1211
Fax: 0161 232 4700

www.dentalhealthunit.org
iain.pretty@manchester.ac.uk

IP/ms

25-Oct-07

Dear Head Teacher,

Re: Dental study taking place in the North East and North West

I am writing to you on behalf of a research team based at the University of Manchester to tell you about a project that we plan to run within schools in Newcastle and Manchester.

Legislative changes in the UK will shortly enable more areas of the country to assess the feasibility of water fluoridation. Prior to the implementation of new schemes it is essential that we can develop better techniques to assess the impact of such a public health measure. As part of the development of strategies to assess such impacts we are testing some new ways of measuring dental decay levels. This has the support of the Medical Research Council. We have chosen Newcastle and Manchester as the sites for our study because they contain clearly defined areas of fluoridated and non-fluoridated water supplies.

One or more schools within your LA will be invited to participate and we wish to seek your approval to run a portion of the study in your school. We would like to arrange to meet you to discuss the project in greater detail and answer any questions you may have.

Children in Year 7 would be asked to participate in a brief dental examination and have a number of photographs taken which will show only their teeth. They would also be asked to complete a 3-day food diary. The study has been approved by the University of Manchester Ethics Committee and all individuals taking part will be provided with information sheets and will have to provide a signed consent form. I have attached these to this letter for your information.

I do hope that this provides you with sufficient information. However, you will have the opportunity to review full protocol and ask questions when we meet. In the meantime please do not hesitate to contact to me at the address above. Contact will be made to arrange an appointment to see you at a convenient time.

Kindest regards

IAIN A PRETTY	GILL DAVIES	MICHAEL MCGRADY

Address Details

Dr Iain A Pretty Senior Lecturer School of Dentistry University of Manchester Skelton House Manchester, M15 6SH	Dr Gill Davies Senior Dental Officer Specialist in Dental Public Health Dept Dental Public Health Mauldeth House Mauldeth Road West Manchester, M21 7RL	Mr Michael McGrady Senior Research Fellow School of Dentistry University of Manchester Skelton House Manchester, M15 6SH

MANCHESTER 1824

The University of Manchester

The Dental Health Unit
3A Skelton House
Manchester Science Park
Manchester
M15 6SH

Dr. Iain A Pretty, BDS, MSc, PhD, MFDS RCS(Ed)
Senior Lecturer in Dental Public Health
Postgraduate Research Trainer

Tel: 0161 226 1211
Fax: 0161 232 4700

www.dentalhealthunit.org
iain.pretty@manchester.ac.uk

IP/ns

25-Oct-07

Chair of LDC

Dear Sir or Madam,

Re: Dental study taking place in the North East and North West

I am writing to you to on behalf of a research team based here at the University of Manchester and Newcastle University to tell you about a project that we intend to run within schools in Manchester and Newcastle.

Legislative changes in the UK will shortly enable more areas of the country to assess the feasibility of water fluoridation. Prior to the implementation of such new schemes, one of which may be based in Manchester, it is essential that as dental researchers we can develop better techniques to assess the benefits of such a public health measure. As part of the development of strategies to assess such benefits we are testing some new ways of measuring dental caries. This has the support of the Medical Research Council. We have chosen Newcastle and Manchester as the sites for our study because they contain clearly defined areas of fluoridated and non-fluoridated water supplies.

Children in your area will be asked to participate in a brief dental examination and have a number of photographs taken – all of which will show only their teeth. The study has been approved by the University of Manchester Ethics Committee and all individuals taking part will be provided with information sheets and will sign an informed consent form. I have attached these to this letter for your information.

As part of this examination we are required to inform the child and their parents of any dental treatment that is deemed necessary. In reality this will relate to grossly carious teeth and signs of sepsis. This could result in an increase in attendance of regular child patients or an increase in requests for new patient exams for dentists within your LDC area. I have attached to this letter a copy of the form that will be returned the child's parents.

Do please contact me if you have any further questions.

Kindest regards

IAIN A PRETTY	**ANNE MAGUIRE**	**MICHAEL MCGRADY**

Address Details

Dr Iain A Pretty Senior Lecturer School of Dentistry University of Manchester Skelton House Manchester, M15 6SH	Dr Anne Maguire Senior Lecturer in Child Dental Health School of Dental Sciences Newcastle University Framlington Place Newcastle, NE2 4BW	Mr Michael McGrady Senior Research Fellow School of Dentistry University of Manchester Skelton House Manchester, M15 6SH

MANCHESTER 1824

The University of Manchester

The Dental Health Unit
3A Skelton House
Manchester Science Park
Manchester
M15 6SH

Dr. Iain A Pretty, BDS, MSc, PhD, MFDS RCS(Ed)
Senior Lecturer in Dental Public Health
Postgraduate Research Trainer

Tel: 0161 226 1211
Fax: 0161 232 4700

www.dentalhealthunit.org
iain.pretty@manchester.ac.uk

IP/ns

25-Oct-07

Head of LEA

Dear Sir or Madam,

Re: Dental study taking place in the North East and North West

I am writing to you to on behalf of a research team based here at the University of Manchester and Newcastle University to tell you about a project that we intend to run within schools in Newcastle and Manchester.

Legislative changes in the UK will shortly enable more areas of the country to assess the feasibility of water fluoridation. Prior to the implementation of such new schemes, one of which may be based in Manchester, it is essential that as dental researchers we can develop better techniques to assess the benefits of such a public health measure. As part of the development of strategies to assess such benefits we are testing some new ways of measuring dental caries. This has the support of the Medical Research Council. We have chosen Newcastle and Manchester as the sites for our study because they contain clearly defined areas of fluoridated and non-fluoridated water supplies.

One or more schools within your LEA will be invited to participate and the approval of the Head Teach will be sought. Children will be asked to participate in a brief dental examination and have a number of photographs taken – all of which will show only their teeth. The study has been approved by the University of Manchester Ethics Committee and all individuals taking part will be provided with information sheets and will sign an informed consent form. I have attached these to this letter for your information.

I do hope that this provides you with sufficient information. However, if you would like sight of the full protocol, or if you have any further questions please do not hesitate to contact to me at the address above.

Kindest regards

IAIN A PRETTY	**ANNE MAGUIRE**	**MICHAEL MCGRADY**

Address Details

Dr Iain A Pretty Senior Lecturer School of Dentistry University of Manchester Skelton House Manchester, M15 6SH	Dr Anne Maguire Senior Lecturer in Child Dental Health School of Dental Sciences Newcastle University Framlington Place Newcastle, NE2 4BW	Mr Michael McGrady Senior Research Fellow School of Dentistry University of Manchester Skelton House Manchester, M15 6SH

The Dental Health Unit

MANCHESTER 1824

The University of Manchester

3A Skelton House
Manchester Science Park
Manchester
M15 6SH

Dr. Iain A Pretty, BDS, MSc, PhD, MFDS RCS(Ed)
Senior Lecturer in Dental Public Health
Postgraduate Research Trainer

Tel: 0161 226 1211
Fax: 0161 232 4700

www.dentalhealthunit.org
iain.pretty@manchester.ac.uk

IP/ns

25-Oct-07

Dear Head Teacher,

Re: Dental study taking place in the North East and North West

I am writing to you on behalf of a research team based at the University of Manchester to tell you about a project that we plan to run within schools in Newcastle and Manchester.

Legislative changes in the UK will shortly enable more areas of the country to assess the feasibility of water fluoridation. Prior to the implementation of new schemes it is essential that we can develop better techniques to assess the impact of such a public health measure. As part of the development of strategies to assess such impacts we are testing some new ways of measuring dental decay levels. This has the support of the Medical Research Council. We have chosen Newcastle and Manchester as the sites for our study because they contain clearly defined areas of fluoridated and non-fluoridated water supplies.

One or more schools within your LA will be invited to participate and we wish to seek your approval to run a portion of the study in your school. We would like to arrange to meet you to discuss the project in greater detail and answer any questions you may have.

Children in Year 7 would be asked to participate in a brief dental examination and have a number of photographs taken which will show only their teeth. They would also be asked to complete a 3-day food diary. The study has been approved by the University of Manchester Ethics Committee and all individuals taking part will be provided with information sheets and will have to provide a signed consent form. I have attached these to this letter for your information.

I do hope that this provides you with sufficient information. However, you will have the opportunity to review full protocol and ask questions when we meet. In the meantime please do not hesitate to contact to me at the address above. Contact will be made to arrange an appointment to see you at a convenient time.

Kindest regards

IAIN A PRETTY **ANNE MAGUIRE** **MICHAEL MCGRADY**

Address Details

Dr Iain A Pretty Senior Lecturer School of Dentistry University of Manchester Skelton House Manchester, M15 6SH	Dr Anne Maguire Senior Lecturer in Child Dental Health School of Dental Sciences Newcastle University Framlington Place Newcastle, NE2 4BW	Mr Michael McGrady Senior Research Fellow School of Dentistry University of Manchester Skelton House Manchester, M15 6SH

MANCHESTER 1824

The University of Manchester

Dental Research Study - Summary

This study is looking into the difference adding fluoride to the water makes to children's teeth.

We are inviting children aged 11 and 12 in schools to take part.

Participation in this study is entirely voluntary and your child may choose to withdraw from the study at any time.

As part of the study your child will;

Agree to take part and sign a form.

Be asked a few questions about tooth brushing and the foods they eat and drink.

Have a dental check up by a dentist.

Have pictures taken of their teeth.

Be given a food diary to complete over three days.

Further information is enclosed and should answer any questions you may have. If you have any further questions or would like to discuss the study please contact Nicola Boothman on 0161 226 1211.

If you do not want your child to take part please complete the pink form and return it in the reply paid envelope.

The Dental Health Unit
3A Skelton House
Manchester Science Park
Lloyd Street North, Manchester
M15 6SH

Dr Iain A Pretty

Tel: 0161 226 1211
Fax: 0161 232 4700

Oral Health Care Study – Parent's Information Sheet

Dear Parent or Guardian

You may recall that we wrote to you recently asking for your consent (agreement) for your child to be involved in a clinical research study that we are conducting in conjunction with the University of Newcastle and the Department of Health. We are now contacting all parents and guardians who did not return consent letters. If you have already done so, please accept our apologies for contacting you again. The study is still in progress and we wish to inform you of our intent to contact the parents and guardians of all the children who have not yet consented to take part. I would like to give you some more information to remind you about the background to the study. I also suggest that you read the information provided to your child to ensure you are happy that it reflects what we aim to do as we will be seeking their consent to take part.

Dental Decay
Dental caries, or decay, is still a major problem within the UK. A number of measures have reduced the amount of decay within certain parts of the population and the most important of these are fluoride in both water supplies and toothpaste. Dental decay often requires a visit to the dentist and the placement of a filling. This will often mean time off school and work for both child and parent. Untreated dental decay can lead to painful toothache which may ultimately require a tooth to be extracted.

Water fluoridation
Many areas of the UK still do not benefit from water fluoridation. Recent changes in the law will enable more local governments to implement water fluoridation if they choose. However, in order for this to take place we will need to have improved methods of assessing the value of adding fluoride to the water. Our research group is interested in developing new ways of looking at tooth decay that will help in evaluating new water fluoridation programmes.

Why is my child being asked to participate?
We are running this study in two areas, one in the North East, the other in the North West. One area is water fluoridated, the other is not. By looking at these different areas we will be able to see the differences that water fluoridation makes to the oral health of the children living in these regions. Your child has not been individually selected – we are asking the parents or guardians of all children aged 11 and 12 in this school if they would like to participate. Your child will be part of a group of approximately 2000 we aim to assess. Participation in this study is entirely voluntary. Your child may choose to withdraw from the study at any time and you do not have to give us a reason. **There is a form enclosed to return to us if you do not wish your child to take part.**

What will happen to my child if they participate in the study?
If you have no objection, and your child wishes to take part in the study they will be contacted at school. We will provide your child with the information that you have been given in this letter to read. We will then talk them through the stages of the study and what will happen to them, allowing them to ask any questions that may arise. If they are happy to take part we will ask them to complete a consent form (also include in this letter). **Your child will only take part if they are happy and willing to do so.** We will do a number of different examinations. The first will be a very standard dental check up where a dentist will look at all of your child's teeth. Next, a few pictures will be taken. The first of these will be done with a very small camera in the mouth and the next two pictures will be taken outside of the mouth; looking only at the front teeth. One of these will be with a standard camera and the other with a special camera which uses blue light. It will be necessary to dry the teeth using some compressed air, just like at a regular dentist's surgery. **None of the photographs will show your child's face – they will only be of their teeth.** We have included an example of the type of photograph we will take below. We will use a simple, harmless plastic lip retractor to hold your child's lips away from their teeth. An image of a retractor is also shown below.

Typical study photograph

Lip retractor

We would expect that all of the examinations will take no more than 30 minutes. All of the examinations are done without any probing of the teeth; just with either a mirror or a camera and are completely painless. At any stage your child can decide that they do not want to continue with the study. After the examinations are done your child will be asked to complete a very simple survey that asks questions on the appearance of teeth, the amount of toothpaste that they use and the size of their toothbrush. After this your child will go back to their classroom. We will ask them to complete a food diary over a 3 day period at home with your supervision and bring the completed diary back into school. We will look at the images we have taken after the study has finished.

For some of the children in the study (a group of approximately 50 children) we will conduct a more detailed questionnaire on their diet history. We will write to you separately about this if your child is selected.

The results of this study may help us to identify children who may be suitable for future studies, if your child is suitable we may contact you again. You and your child would not be under any obligation to take part in any future studies.

Where will all these photographs be kept and who has access to them?
We will store all the photographs and clinical information on computers that are secured with a password. None of the information that we collect will be linked to your child, i.e. the information will be anonymous. The only people to have access to the information are the scientists involved in the study. We hope to publish our results in a scientific journal. No information concerning your child will be included. We will provide a copy of the results to your child's school if you would like to see them. The study may be monitored by external bodies such as the ethics committee or regulatory authorities. Once again, your child will not be identified during this process.

What if my child has something wrong with their teeth?
If the examining dentist notices something in your child's mouth that they feel needs treating they will write to you and let you know. You can take this letter to a dentist and they will be able to advise you further.

What benefit is there to me or my child?
This study aims to understand better the link between the reduction in tooth decay and water fluoridation. Your child will be helping us to develop more information on this important issue. Your child may not gain a direct benefit by taking part in this study but they will receive a full dental examination and this may help identify any problems that they have. Once your child has returned the completed food diary they will be given a toothbrush and toothpaste to thank them for their help. There are no risks to your child taking part in this study. All of the procedures and equipment being used have a safe history of use and have been used in studies before. In the unlikely event that something does go wrong and your child is harmed during the research and this is due to someone's negligence then you may have grounds for a legal action for compensation against the Local Education Authority or the University of Manchester, but you may have to pay your legal costs.

The University of Manchester has cover for no fault compensation for bodily injury, mental injury or death where the injury resulted from a trial or procedure you received as part of the trial. This would be subject to policy terms and conditions. Any payment would be without legal commitment. (Please ask if you wish more information on this). The University would not be bound to pay this compensation where the injury resulted from a drug or procedure outside the trial protocol or the protocol was not followed.

Who is paying for this study?
The University of Manchester is the study sponsor and the funding is sourced from the Department of Health.

Who has reviewed this study?
This research has been looked at by an independent group of people called a research ethics committee to protect the safety, wellbeing, rights and dignity of you and your child. This study has been reviewed and given a favourable opinion by the University of Manchester Committee on the Ethics of Research on Human Beings. We also have the support of the Local Authority and school.

Who is running this study, what if I have a question?
The study is being undertaken by researchers at the Universities of Manchester and Newcastle. In

Manchester Dr Iain Pretty is the principle investigator, and in Newcastle, Dr Anne Maguire is leading the team. If you have any questions regarding the study please feel free to contact one of the following:-

For Newcastle – Debora Howe on 0191 219 5217 email Debora.Howe@newcastle-pct.nhs.uk
For Manchester - Nicola Boothman on 0161 226 1211 email Nicola.Boothman@manchester.ac.uk

What do I do now?
If you are happy for your child to take part you do not need to do anything. We will contact the school to arrange a visit in school. **If you do not wish your child to take part please complete the consent form that is attached to this letter. This is very important. We have enclosed a prepaid envelope for you.**

I would like to thank you for reading this information sheet and considering your child's inclusion in the study. Do please contact Nicola Boothman (Manchester) or Debora Howe (Newcastle) if you need any more information.

Yours Sincerely

Dr Iain Pretty

Address Details

Dr Anne Maguire
Senior Lecturer
Dental School
Newcastle University
Framlington Place
Newcastle, NE2 4BW

Dr Gill Davies
Senior Dental Officer
Specialist in Dental Public Health
Dept Dental Public Health
Mauldeth House
Mauldeth Road West
Manchester, M21 7RL

Mr Michael McGrady
Senior Research Fellow
School of Dentistry
University of Manchester
Skelton House
Manchester, M15 6SH

The University of Manchester

The Dental Health Unit
3A Skelton House
Manchester Science Park
Lloyd Street North, Manchester
M15 6SH

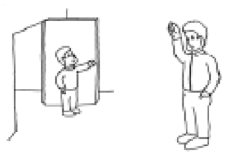
Dr Iain A Pretty

Tel: 0161 226 1211
Fax: 0161 232 4700

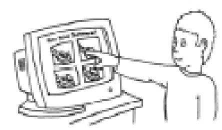
Oral Health Care Study – Child's Information Sheet

Dear Student

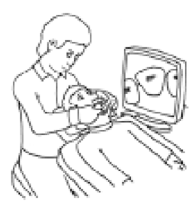
I am writing to ask you if you would like to take part in a research project (study) that I and some scientists from Newcastle University are running in Newcastle and Manchester. I have also written to your parents or guardian. The first thing we will do is to make sure your parents have said it is ok for you to take part.



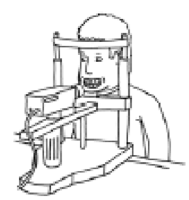
1. We would like you to help us look at tooth decay and white patches on teeth in school children about your age. We will look at 1000 children from Newcastle and 1000 children from Manchester



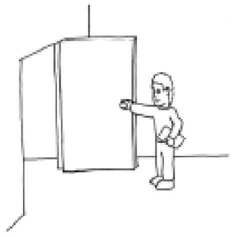
2. We will ask you to use a computer screen to show us how big your toothbrush is, how much toothpaste you use, and how you rinse your mouth when you brush your teeth



3. We will look in your mouth like a normal check-up at the dentist. We will use a special camera to take pictures of your teeth – which you will be able to see on a computer screen



4. After we have taken pictures inside your mouth we will take more pictures with a different camera. These pictures will be of only your front teeth using a special camera with a frame to support your head in the right place



5. When we have finished taking pictures you can go back to class. Taking all of the pictures will last about 30 minutes. We will give you a food and drink diary to take home. This diary is for you to write down everything you have to eat and drink, it helps us to know the types of food that you eat and drink and how it might affect your teeth

6. You can ask your parents to help you fill in your diary at home. Remember to write down everything you have to eat and drink on each of the days!

7. When you have finished your food diary you can bring it back to school. We will give you a toothbrush and toothpaste to say thank you for helping us.

If you have any questions please ask us, if you do not want to take part, you do not have to. It is up to you!

Thanks again!

Iain Pretty

Address Details

Dr Anne Maguire
Senior Lecturer
Dental School
Newcastle University
Framlington Place
Newcastle, NE2

Dr Gill Davies
Senior Dental Officer
Specialist in Dental Public Health
Dept Dental Public Health
Mauldeth House
Mauldeth Road West
Manchester, M21 7RL

Mr Michael McGrady
Senior Research Fellow
School of Dentistry
University of Manchester
Skelton House
Manchester, M15 6SH

MANCHESTER 1824

The University of Manchester

Child's name and School (Will be printed here)

PARENTAL OPT OUT FORM

If you **do not** want your child to take part in the dental study please sign below and return it to us in the pre-paid envelope.

"I do not want my child to take part in the dental Study"

Signature: ____________________Date: __________

Relationship to Child (Parent/Guardian):___________

Child and School ID to be printed here for Office Purposes

MANCHESTER 1824

The University of Manchester

Oral Health Care Study

CONSENT FORM

Adhesive label to contain the following information;

School & ID

Address

POSTCODE:

Student to circle all they agree with:

Have you read (or had read to you) about this project?	Yes/No
Has somebody else explained this project to you?	Yes/No
Do you understand what this project is about?	Yes/No
Have you asked all the questions you want?	Yes/No
Have questions been answered in a way you understand?	Yes/No
Do you understand it's OK to stop taking part at any time?	Yes/No
Are you happy to take part?	Yes/No

If any answers are 'no' or you don't want to take part, don't sign your name!

If you do want to take part, you can write your name below

Your name ______________________________

Date ______________________________

Thank you

Signature of Investigator:

____

Child's name and school will be printed here