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Review Article

Methods and indices in measuring fluorosis: A review

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Abstract Fluorosis is important to measure because it is a condition that can be used as biomarker for the level of fluoride exposure during enamel formation. Increased and decreased in fluorosis prevalence may also reflect to the different ways of measuring the disease. The choice of measuring fluorosis is depends on the objective of the assessment such as assessing public health significant of fluorosis in the population or assessing the detailed of biological effects of fluoride. These differences in requirement have led to the adoption of many indices and assessment methods of enamel fluorosis, which subsequently led to evaluation of examiner agreement between them. Several indices were developed to measure dental fluorosis in the 20th century. These include fluorosis specific indices such as Dean's Index; the Thylstrup and Fejerskov Index; the Total Tooth Surface Index; and the Fluorosis Risk Index. Non-specific descriptive indices such as the Developmental Defects of Enamel index have also been used to record fluorosis. Fluorosis has most commonly been recorded using clinical examinations and photographs. Recent developments have seen the use of a Visual Analog Scale and automated grading systems such as Quantitative Light Fluorescence emerge as possible enhancements to fluorosis scoring. This article aims to review existing indices and new methods in measuring dental fluorosis, together with examiner reliability across different methods and indices.

Keywords: dental fluorosis, epidemiology, examiner reliability, imaging technique, indices.

Introduction

Dental fluorosis describes a condition where tooth enamel has a reduced mineral content caused by a high intake of fluoride during the critical tooth formation period in early life (Dean, 1934; Clarkson, 1989; Fejerskov *et al.*, 1990). Dental fluorosis has a broad spectrum of clinical and histological presentation. Clinically, in its mild form, fluorosed enamel appears as diffuse white spots or lines, has a white parchment-like appearance (Browne *et al.*, 2005). The white striations run horizontally across the enamel surface and are symmetrically distributed. This degree of fluorosis does not impact on the function of the tooth. In moderate to severe cases, fluorosed enamel appears pitted, and discoloured. At this level of severity the tooth is more prone to wear and fracture (Fejerskov *et al.*, 1990; Mascarenhas 2000; Buzalaf and Levy, 2011). Histologically, fluorosed enamel is characterised by hypomineralised and subsurface porosity (Fejerskov *et al.,* 1977). In the mild form, the structural arrangement of the crystals in the outer layer of enamel is normal, but has increased porosity. In more severe forms, the hypomineralised lesion is located deeper to a well mineralized surface zone which is very fragile and is susceptible to mechanical stress (Baelum *et al.*, 1986; Fejerskov *et al.*, 1990).

Fluorosis is important to measure because it is a condition that reflects the level of fluoride exposure during enamel formation and this condition should be monitored regularly (O'Mullane *et al.*, 2016). When fluorosis condition is found to be a significant extent in a community, steps should be taken to reduce fluoride intake by children with developing teeth. However, increased and decreased in fluorosis prevalence may also reflect to the different ways of measuring the disease. For example, a study that considers public health significant of fluorosis would have different requirements to one assessing the detailed biological effects of fluoride. The

diagnosis of fluorosis is also crucial in particular to differentiate fluorosis condition, which is enamel defect cause by fluoride or other enamel defects that causes by a variety of other causes such malnutrition, caeliac disease, rickets and premature birth (Browne *et al.*, 2005). These differences in requirement have led to the adoption of many indices and assessment methods of enamel fluorosis. Given to the plethora of fluorosis indices and methods, several studies had evaluated the examiner agreement between them, however newer fluorosis measurement received less attention. Therefore this paper aims to review existing indices and new methods in measuring dental fluorosis, together with examiner reliability across different methods and indices.

Measurement indices

Several indices were developed to measure dental fluorosis in the 20th century. These include fluorosis specific indices such as Dean's Index (DI); the Thylstrup and Fejerskov (TF) Index; the Total Tooth Surface Index (TSIF); and the Fluorosis Risk Index (FRI). Non-specific descriptive indices such as the Developmental Defects of Enamel (DDE) index have also been used to record fluorosis. Researchers have extensively discussed and criticised each index. The different types of indices along with their advantages and disadvantages are summarised in Table 1.

The methods of measuring fluorosis

Direct clinical examination and imaging techniques are the most common methods used to measure fluorosis.

Direct clinical examination

Clinical examination is widely used because it is fast, easy, cost-effective, all tooth surfaces can be examined and tactile examination can also be performed (Golkari *et al.*, 2011). However, the clinical assessment is often associated with disadvantages such as the method of examination, lighting conditions, examiner bias and examiner reliability (Ellwood *et al.*, 1994; Cochran *et al.*, 2004a; Whelton *et al.*, 2004). In addition, direct clinical examination is highly dependent on subject cooperation especially when several indices are employed at the same time.

Imaging techniques

To overcome such weaknesses in clinical examination, imaging techniques have been developed. These provide a permanent record of the enamel surface for fluorosis assessment. The main advantages of using images are it allows blinding of the examiner(s), which minimise examiner bias, and archiving of the images allows repeated measurement by multi-examiners at a location remote from the clinical examination sight. Permanent record provided by photographs can also be kept for longitudinal assessment, future measurement using different indices and training of examiners (Cochran *et al.*, 2004a).

The disadvantages of imaging methods are firstly that they are technique sensitive, and variation can be introduced by the technique used to take the image, the camera equipment and the quality of the image produced. Secondly, there is an issue with specular reflection caused by the ring flash used to provide adequate lighting. This can result in over reporting prevalence of dental fluorosis (Cochran *et al.*, 2004a; Soto-Rojas *et al.*, 2008). This is mainly due to the appearance of reflections from the flash that might mimic the appearance of white spot lesions. Thirdly, it is only suitable for anterior teeth, photographic access to posterior teeth being poor. Although several researchers have proposed multi-view techniques to overcome these problems (Wong *et al.*, 2005), some surfaces or part of the surfaces may be missed even using multiple views (Golkari *et al.*, 2011). This could result in under reporting the prevalence of fluorosis as compared to whole mouth examination. Finally, the use of photographs adds to the cost of the study, when compared with a clinical examination alone.

Imaging techniques in assessing fluorosis can be divided into conventional and digital photography. In the early introduction of imaging techniques for

fluorosis assessment, conventional photography was often used (Nunn *et al.*, 1993; Ellwood *et al.*, 1994; Sabieha and Rock, 1998). Although photographic methods have evolved from conventional transparencies using film to digital images, some researchers still prefer to use conventional photography to enable data comparison with different studies that used the same standardized methods (Cochran, *et al.*, 2004a; Cochran *et al.*, 2004b; Wong *et al.*, 2014).

In recent years, several researchers have reported fluorosis assessment using digital photography (Tavener *et al.*, 2007; Martins *et al.,* 2009; Golkari *et al.*, 2011; Cruz-Orcutt *et al.*, 2012; Mohd Nor *et al.*, 2016). The main benefits of using digital photography are that it allows the examiner to evaluate the quality of the image captured during the clinical examination immediately post exposure. It can therefore be repeated if the quality of the image is not acceptable. In addition, digital photography also allows the examiner to zoom and adjust to capture the best image instead of using a fixed barrel lens (Golkari *et al.*, 2011). It is suggested that digital photography can more easily accommodate patient confidentiality and can be stored in digital systems. Images are, produced instantaneously and do not require developing of negatives and printing. The disadvantages are the increased cost of the equipment and require an experienced and photographer trained in using a digital camera (Cochran *et al.,* 2004a; Martins *et al.,* 2009).

It has been suggested that advances in intra-oral imaging have overcome some of the previous, weaknesses with photographic methods such as specular reflection, by using polarizing filters (Robertson and Toumba, 1999). There are two polarization techniques. The first technique, uses a single polarizing filter placed in front of the light source (i.e. ring flash). The second technique, uses two linear polarizing filters (cross polarization), one placed on the lens and the other in front of the light source. Although polarization technique can eliminate unwanted reflection, it has been argued that the specific assessment of dental fluorosis using this technique may not be suitable because the surface detail of enamel is lost (Soto-Rojas *et al.*, 2008). Cross polarisation also produces an air-brushed effect, a frosty appearance and loss of colour balance (Robertson and Toumba, 1999). In addition, it has been reported that this technique may create unnatural images in dental photography (Bengel, 2006). Another alternative method of reducing the reflections is to take photographs at an angle to ensure that the flash is not reflected back into the lens (Cochran *et al.*, 2004a; Pretty *et al.*, 2012). However this technique may be subject to variability in the angle at which the camera is held and may lead to bias in operator standardisation.

New approaches in fluorosis measurement

As photographs act as a valid method to measure fluorosis, a Visual Analog Scale (VAS) has been developed based on aesthetic perceptions of the photographs using a 100 millimetre (mm) continuous scale (Vieira *et al.*, 2005). The 100-mm scale was graded based on best and worst spectrum of enamel surface (i.e. on left end of the scale labelled as 'best you can imagine' and the right end labelled as 'worst you can imagine'). Five photographs of fluorosis with a range of severity of dental fluorosis were used as scale indicators. The benefits of using a VAS over other indices are the continuity of the scale and its simplicity of use. It was reported that the continuous scale may provide more robust and meaningful parametric analyses. Conversely, the existing indices for dental fluorosis are based on ordinal data which makes quantification difficult and potentially requires complicated statistical analysis. Although the development of the new scale aims to improve previous indices, it is not without limitations. The main criticism of the VAS is that it does not have specific criteria for its scale points which are prone to examiner bias. Although photographs of fluorosis with a range of severities of dental fluorosis were used as indicators, the assessment is still considered very subjective which may lead to difficulty in examiner training and calibration. Since the

development of the scale in 2005, only two studies reported using VAS (Vieira *et al.*, 2005; Ramya *et al.*, 2014). Further research is required to assess validity and feasibility of the scale in epidemiology studies.

Despite significant advantages of clinical photography over direct clinical examination, visual scoring is still subjective and prone to the effects of personal thresholding in particular at low levels of fluorosis severity. Another concern is the variability in inter and intra-examiner agreement when different indices are used. In 2006, a new approach was developed by Pretty and colleagues to overcome these pitfalls by assessing dental fluorosis using an automated grading system namely quantitative light fluorescence (QLF) (Pretty *et al.*, 2006). The principle of QLF is to compare changes in fluorescence between sound enamel and 'unsound enamel' (loss of fluorescence intensity in areas of enamel hypomineralisation). Images were assessed by computer software.

However, the main limitation of QLF is the inability to differentiate mineral loss as a result of fluorosis or other forms of enamel defects. Other features such as caries, restorative material or extrinsic staining also interfere with the QLF analysis. In 2012, Pretty *et al.* proposed another technique namely a dual imaging system, which is a combined method between fluorescent imaging and polarized white light (Pretty *et al.*, 2012). Polarization provides better images which eliminate the specular reflection for assessment using an automated grading system. Additional advantages of using this dual camera system are the ability to facilitate the use of an automated system and minimise the need for photographic training. Authors claimed as the technique being easy to operate and well accepted by the subjects. This system is relatively new and is ambitious in fluorosis assessment. Further research is needed to understand the feasibility of using this surveillance system in epidemiology settings to determine wider applicability. Its cost-effectiveness is also unknown.

Examiner reliability across different methods and indices

There are a number of fluorosis studies that have assessed examiner reliability using different examination methods and indices. Table 2 summarises the studies into four categories: clinical examination alone, photographic method alone, clinical examination versus photograph examination and clinical examination versus digital photographs and fluorescence images. It is difficult to compare data across studies because of the differences in the clinical methods, photographic technique, photograph/ transparency viewing methods, indices used and the case definition used for fluorosis prevalence. In the following comparisons these limitations should be borne in mind.

Results vary across studies with majority of the studies reported as of substantial to excellent examiner reliability, regardless which indices were used to assess fluorosis clinically. When fluorosis severity was measured using photographs alone, some studies did not demonstrate good examiner reliability resulting in kappa scores of less than 0.6 especially in multi–centre studies and when more than six examiners were used (Cochran *et al.*, 2004b; Tavener *et al.*, 2007). This could be due to the variation in conventional transparencies produced by different examiners (Cochran *et al.*, 2004b) and variation in viewing conditions when digital images were assessed remotely (Tavener *et al.*, 2007). Most studies reported substantial examiner reliability between clinical examination and photographic methods, with one study indicating higher fluorosis prevalence using photographs. The difference in findings may have been due to the effect of teeth drying (either purposely drying or natural drying) prior to taking the photograph. In a dry or partially dry state, the contrast between normal and abnormal enamel contrast may be enhanced which result in a difference in recorded prevalence. New approaches such as the quantitative light fluorescence technique was also reported as having good examiner reliability when it was compared with clinical examination and polarized white light photographs either using Deans or TF index.

Table 1 Summary of the advantages and disadvantages of fluorosis indices

Index/ Authors	Advantages	Disadvantages
Dean's Index (DI) (Dean, 1934)	Simple to use; accepted at global level; long track record of use supported by literature; allow historical comparison with old studies; recognized by World Health Organization for use in oral health surveys basic method; teeth are examined wet - more relevance to concerns in a public health context (Elwood *et al.* 1994).	Only measure the two most severely affect teeth, does not allow measurement of fluorosis on different tooth surfaces; no information about location of affected teeth; the diagnostic category for 'questionable' in the classification is unclear and lacks precision; the index lacks sufficient precision to distinguish different degrees of fluorosis; teeth are examined wet-may overlook minor opacities (Horowitz, 1986; Clarkson 1989; Rozier, 1994).
Thylstrup- Fejerskov (TF) Index (Thylstrup and Fejerskov, 1978)	Record histological changes that occur in dental fluorosis based on an ordinal scale which allows sufficient precision to distinguish different degrees of fluorosis; TF index has been validated clinically and histologically; TF index is as commonly used as Dean's Index and is particularly favoured in European studies; teeth are examined dry - improve diagnostic sensitivity (Pretty *et al.*, 2006).	Difficult to standardize tooth dryness; the effect of drying may reveal a short period of changes which have less aesthetic or public health importance; the criteria for score 1 and 2 describe only very minor changes. (Clarkson, 1989).
Developmental Defect of Enamel (DDE) Index (FDI, 1992)	Detail measurement that includes a broad range of defects with information on the distribution and location; teeth are examined wet - more relevance to concerns in a public health context. (Elwood *et al.* 1994).	Teeth are examined wet-may overlook minor opacities; time-consuming to conduct due to large information collected.
Tooth Surface Index of Fluorosis (TSIF) (Horowitz *et al.,*1984)	A score is given to all surfaces instead of individual teeth; the index improves diagnostic sensitivity for fluorosis in severe categories; the index permits a distinction between discrete pitting and more advance confluent pitting and staining alone and staining with pitting; the index is useful especially in populations where severe fluorosis is prevalent; teeth are examined wet - more relevance to concerns in a public health context.	Scoring all surfaces may increase surface-to-surface variation between examiners; scoring lingual and hard to see surfaces may reduce examiner consistency; possibility of losing data on occlusal surfaces because of restorations; teeth are examined wet-may overlook minor opacities (Rozier, 1994).
Fluorosis Risk Index (FRI) (Pendrys, 1990)	The scoring system of different zones of a tooth surface; allow identification of risk factors of fluorosis; useful for analytical epidemiology studies because it allows identification of age-specific exposure to fluoride sources and development of enamel fluorosis (Rozier, 1994).	The index is complex for its biological perspective and application; suitable to estimate of relative risk of fluorosis rather than fluorosis prevalence; the many surface zones to be scored may lead to the possibility of misclassification and increase surface variation both within and between examiners (Rozier, 1994).

Table 2 Studies of examiner reliability in measuring fluorosis using different examination methods and indices

Reference	Country	Age group	Index	Tooth examined	Number of examiner	Findings
Clinical examination only						
Mabelya *et al*., 1994	Tanzania	11-18	TF, DI	All fully erupted permanent teeth	2	Kappa score (intra-examiner) for TF: 0.69 (overall), 0.83 (weighted kappa), 0.84 (anterior), 0.82 (posterior). Kappa score (intra-examiner) for DI: 0.70 (overall), 0.87 (weighted kappa), 0.87 (anterior), 0.86 (posterior). Fluorosis prevalence: community with low fluorosis [DI: 3%, TF: 11%], community with moderate fluorosis [DI: 36%, TF:46%], community with high fluorosis [DI: 95%, TF: 98%]
Pereira and Moreira, 1999	Brazil	12-14	DI, TF, TSIF	All fully erupted permanent teeth	1	Kappa score (intra-examiner): DI:0.76, TF:0.79, TSIF:0.78 Fluorosis prevalence: Cesario Lange [DI: 32.9%, TF: 33.5%, TSIF:32.8%] Piracicaba: [DI:16.9%, TF: 17.6%, TSIF:16.9] Iracemapolis: [DI: 4.2%, TF: 4.2%, TSIF: 4.2%]
Kumar *et al*., 2000	USA	Grade 1 to 8	DI	All fully erupted permanent tooth	3	Kappa score (Inter-examiner) for presence and absence of dental fluorosis: 0.75to 0.94. Kappa score at subject level: 0.67 to 0.76. Fluorosis prevalence: 15% to 21%
Photographic examination only						
Ellwood *et al*., 1994	Wales & England	14	TF, TSIF, DDE	Upper incisors, left and right first bicuspid, cuspid and lateral incisors (8 teeth)	Multiple examiner (specific numbers not stated)	Kappa score (intra-examiner): TF: 0.49 (tooth score), 0.58 (mouth score) TSIF: 0.71 (tooth score), 0.85 (mouth score) DDE: 0.78 (tooth score), 0.94 (mouth score) Fluorosis prevalence: TF ≥1: 31.5%- 51% DDE (diffuse opacities): 4.5%- 12.9% TSIF≥1 : 10-20.6%
Cochran *et al*., 2004b	Europe (7 sites)	8	DDE, TF	Maxillary central incisors	7	Kappa score for DDE: [Intra-examiner: 0.43 to 0.70]; [Inter-examiner: 0.34-0.69]. Kappa score for TF: [Intra-examiner: 0.45 to 0.66]; [Inter-examiner: 0.32-0.55]. Fluorosis prevalence: not stated
Tavener *et al*., 2007	England	8-10	TF	Upper & lower anterior sextants	10	Agreement between 10 examiners using digital photographs in a Power Point presentation at different location. Inter-examiner Kappa score: 0.40 to 0.71. Fluorosis prevalence (TF>0): 43%-70%.

Table 2 (continued)

Reference	Country	Age group	Index	Tooth examined	Number of examiner	Findings
Clinical versus photographic examination						
Cruz-Orcutt *et al.*, 2012	USA	13	FRI	Maxillary incisors	3	Kappa score (clinical vs photographs): 0.46 Higher fluorosis prevalence using photographs (33%) than clinical examination (18%)
Martins *et al.*, 2009	Brazil	7-9	Not stated	Central incisors	4	Kappa score (clinical vs photographs): 0.67. Higher fluorosis prevalence using clinical examination (49%) than photographs (36.7%).
Mohd Nor *et al.*, 2016	Malaysia	9 and 12	DI	Upper central incisors	3	Kappa score (clinical vs photographs): 0.74 to 0.77. Higher fluorosis prevalence using clinical examination (30%) than photographs (23% to 26%).
Clinical versus digital photographs and fluorescence images						
Pretty *et al.*, 2006	Ireland	10	TF	Upper left central incisors	1	Kappa score for intra-examiner reliability: Clinical vs fluorescence image: 0.49 Photographs vs fluorescence image : 0.74
Pretty *et al.*, 2012	Thailand	11	TF and DI	Upper left central incisors (clinical vs QLF vs PWL)	4	Clinical vs Quantitative light fluorescence (QLF) & polarized white light (PWL) Clinical vs QLF Spearman correlation: TF :0.73-0.74, DI: 0.78-0.80 QLF vs PWL Spearman correlation: TF: 0.74-0.78, DI: 0.81-0.87
				Upper central and lateral incisors (clinical vs WL vs PWL)		Clinical vs digital photographs [white light (WL) & polarized white light (PWL)]. Kappa score for intra-examiner reliability: Clinical vs PWL: [TF: 0.55-0.54], [DI: 0.64-0.66] Clinical vs WL: [TF: 0.51-0.58], [DI: 0.65] PWL vs WL:[TF: 0.69-0.72], [DI: 0.72-0.92]

DI=Dean's Index, TF=Thylstrup and Fejerskov Index, TSIF=Tooth Surface Index of Fluorosis, FRI=Fluorosis Risk Index, DDE=Developmental Defects of Enamel. F=fluoride, NF=non-fluoridated.
Fluorosis prevalence varies across studies, the prevalence data extracted according to fluorosis case definition reported in each paper.
Kappa score interpretation based on the definition by Landis and Koch (1977). Kappa values 0.81-1.0 (excellent agreement), 0.61-0.80 (substantial), 0.41-0.60 (moderate agreement), 0.21-0.40 (fair agreement), less than 0.20 (poor agreement).

Conclusions

Irrespective of which indices and methods are used to measure fluorosis, none are without limitations. Potential new approaches to measuring fluorosis are more complex than the traditional clinical or photographic methods and further research is needed to determine the possible advantages of these techniques.

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