In vivo Reliability of an Infrared Fluorescence Method for Quantification of Carious Lesions in Orthodontic Patients

Abdulaziz Aljehani[a]/Mohammad Bamzahim[a]/Mirgani Awad Yousif[b]/Xie-Qi Shi[a]

Abstract: The aim of this study was to evaluate the reliability of a laser-induced infrared fluorescence method, DIAGNOdent, for measuring orthodontically induced white spot lesions.

The subjects comprised 13 orthodontic patients, aged 13-17 years, who had recently completed fixed appliance therapy: 137 test teeth were selected, with white spot lesions on the facial or buccal smooth surfaces. An initial visual inspection was performed to localise and record the measuring region. The predetermined measuring regions were scanned to locate the sites of the highest reading. The readings and their corresponding sites were registered on the print out photographs. Following the measurement by the first examiner, the second and the third examiners took DIAGNOdent readings independently at the same lesion sites indicated on the photographs, under identical conditions. One week later, DIAGNOdent readings of the same lesions were retaken by the three observers working independently. Intra- and inter- examiner agreements on DIAGNOdent quantification of lesion severity were analysed by Intra-class correlation coefficient (ICC).

The ICC values for intra-examiner agreement for the three examiners were 0.91, 0.97, and 0.98, respectively, with a mean value of 0.95, indicating excellent agreement. The ICC values for inter-examiner agreement were comparatively lower: 0.69 and 0.82 for the first and second measurements, respectively.

It was concluded that the reliability of the DIAGNOdent readings on white spot lesions associated with orthodontic banding was good.

Key words: fluorescence, caries, smooth surface, reliability

Oral Health Prev Dent 2006 4:145-150. *Submitted for publication: 18.7.05; accepted for publication: 15.11.05.*

Enamel demineralisation is an undesirable but common sequel to orthodontic fixed appliance therapy. Several studies have reported a significant increase in the prevalence and severity of demineralization of dental hard tissue after orthodontic therapy (Gorelick et al, 1982; Øgaard et al, 1988, Boersma et al, 2005). Difficulty in plaque removal leads to prolonged accumulation and retention of bacterial metabolites around fixed orthodontic appliances, resulting in enamel demineralisation, so-called white spots. Studies have shown a significant increase in the number of micro-organisms, such as mutans streptococci and lactobacilli (Lundström and Krasse, 1987a,b; Chang et al, 1999), which is associated with the initiation of dental caries and further development of the carious lesion.

On removal of the bands and brackets at the end of active orthodontic treatment, clinical examination discloses the presence of these lesions, which may range in severity from incipient, non-cavitated to advanced lesions. While minor lesions may be aesthetically disturbing, advanced lesions may require restorative

[a] *Department of Cariology and Endodontology, Institute of Odontology, Karolinska Institutet, Huddinge, Sweden* [b]*Department of Orthodontics, King Abdulaziz Hospital, Makkah, Saudi Arabia*

Reprint requests: *Xie-Qi Shi, Department of Cariology and Endodontology, Institute of Odontology, Box 4064,141 04 Huddinge, Sweden. Tel: 46 8 52488184. Fax: 46 8 7467915. E-mail: xie.qi.shi@ofa.ki.se*

treatment (Basdra et al, 1996; Gorton and Featherstone, 2003).

While the problem may be minimised by strategies to prevent initial demineralisation during fixed appliance therapy, it is important that, after removal of the bands and brackets, the clinician undertakes meticulous examination of the smooth surfaces at risk of caries. The method of choice for registering the lesions should be one that offers reliable detection and assessment of early lesions. The data thus obtained should complement visual assessment as a basis for decision-making with respect to clinical management of any white spot lesions that may have developed during appliance therapy.

There is growing recognition that conventional qualitative methods of assessment of white spot and incipient smooth surface lesions are an inadequate basis for modern, non-invasive clinical caries management. As a complement to conventional methods, in 1998, laser-based fluorescence method, DIAGNOdent (KaVo, Biberach, Germany) was introduced for the purpose of detection and monitoring progression of early caries.

Hibst and co-workers (Hibst and Gall, 1998) found that when the tooth is illuminated by laser light at 655 nm, the difference in fluorescence intensity of sound and carious tissue around 740 nm is most pronounced. This is the mechanism underlying the DIAGNOdent system (Hibst et al, 2001): fluorescence from the measuring site is captured and transmitted via an optical fibre to a hand probe and displayed as a nominal value ranging from 0 (minimum fluorescence) to 99 (maximum fluorescence). The presence of caries is indicated by increased fluorescence intensity. The cause of the fluorescence is still unclear, but proto-porphyrins and meso-porphyrins, bacterial metabolites, probably play a major role (Hibst et al, 2001).

Reliability is an important aspect of the assessment of a diagnostic modality, especially for clinical and epidemiological application and may be expressed in terms of intra- and inter-observer agreement. (Nyvad et al, 1999). In clinical studies, good observer agreement is essential for ensuring reproducible measurements, which provide a basis for any general conclusions to be drawn about the study population or the sample examined.

The DIAGNOdent system is relatively new, and to date both in vivo and in vitro studies of reproducibility have been limited mainly to occlusal surfaces (Lussi et al, 1999, 2001; Shi et al, 2000; Attrill and Ashley, 2001; Alwas-Danowska et al, 2002; Bamzahim et al, 2002; Heinrich-Weltzien et al, 2002; Anttonen et al, 2003, 2004; Francescut and Lussi, 2003; Lussi and Francescut, 2003; Reis et al, 2004; Tranaeus et al, 2004). Most of these studies indicated good to excellent reproducibility. DIAGNOdent measurements and visual examination by an experienced dentist agreed fairly well (Alwas-Danowska et al, 2002).

DIAGNOdent has recently been tested in vitro for quantification of lesions adjacent to fixed orthodontic appliances (Staudt et al, 2004; Aljehani et al, 2004). The results suggested that the DIAGNOdent method might be appropriate for early detection and assessment of white spot lesions in orthodontic patients.

Recent studies by Anttonen, Seppä and Hausen (2003, 2004) and Skold-Larsson et al (2004) support the application of the method for detection and monitoring of fissure caries. By analogy, the method should also be appropriate for detection and monitoring of white spot lesions on smooth surfaces in orthodontic patients after fixed appliance therapy. To our knowledge there are to date no published studies evaluating the clinical application of DIAGNOdent for this purpose.

The aim of the present study was to evaluate the reliability of DIAGNOdent, expressed as intra- and inter-observer agreement, for measuring white spot lesions in orthodontic patients after fixed appliance therapy and to relate the results to those of visual examination.

MATERIALS AND METHODS

The study was approved by the Ethics Committee at Huddinge University Hospital, Huddinge, Sweden (564/03).

Thirteen patients were recruited from King Abdulaziz Hospital, Saudi Arabia, aged 13-17, with a total of 137 test teeth. The subjects were selected from orthodontic patients who had recently completed full fixed appliance therapy (standard edgewise technique), with an average treatment time of two years.

All participants and their parents were informed about the purpose of the study and the study procedure, and informed proxy consent was obtained from all subjects before the start of examination.

After completion of debonding and debanding, a full-mouth cleaning with a rotating rubber cup and water, if necessary, professional supragingival scaling was performed to remove plaque, calculus and any remaining composite bonding material. Caution was exercised to avoid disturbing the lesions.

Visual Examination

Visual examination was performed by three examiners, two cariologists and one orthodontist, together in order to localise the measuring region and to perform caries assessment by visual inspection. In case of disagreement, consensus was reached. Visual inspection was performed after the tooth surfaces were dried with a five-second stream of compressed air with the help of mouth mirrors and blunt probes under clinical lighting, according to the modified Ekstrand criteria and classification presented in Table 1 (Ekstrand et al, 1997). The inclusion criterion was the presence on a smooth surface of a white spot lesion adjacent to the site of the orthodontic band or bracket. Teeth with fluorosis, tetracycline staining or stains of other origin were excluded since the device was very sensitive to the presence of stain, deposits and calculus, which can lead to erroneous readings. The study sample finally comprised 137 teeth: 72 were anterior teeth and 65 posterior teeth.

Fig 1 demonstrates a clinical view of a typical site. At the first visit, the test surfaces of all teeth in the study were documented with a digital camera (Nikon COOLPIX 4500, Japan). The images were saved in a PC and printed out on paper to facilitate the measurements with DIAGNOdent at the second visit.

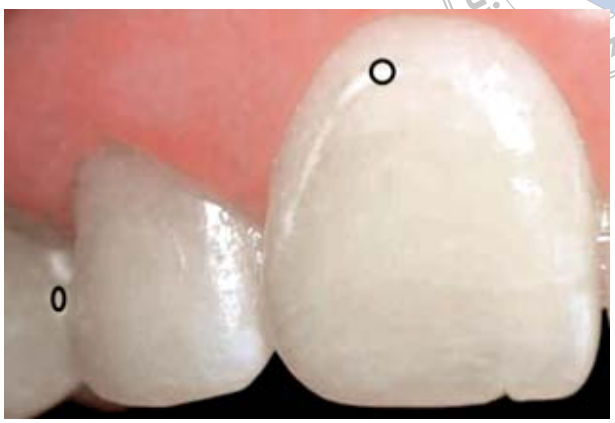

Fig 1 An example of a lesion in the study after removal of orthodontic brackets

DIAGNOdent Measurements

Training and Calibration of Examiners

Prior to the study, the examiners underwent theoretical and practical training in the DIAGNOdent method. Calibrations of DIAGNOdent measurements between observers were carried out for a one-week period, first on extracted teeth and then clinically. Ten extracted teeth with non-cavitated carious lesions were used for calibration exercises. DIAGNOdent measurements of the lesions were repeated and Intra-Class Correlation (ICC) values were calculated in order to ensure an acceptable level of agreement between and within examiners before proceeding to training in clinical application of the device. At the end of training for examiner calibration, intra-examiner agreement for the three examiners was 0.92, 0.94 and 0.96 respectively in extracted teeth, and inter-examiner agreement for the first and second measurements was 0.87 and 0.90 respectively.

One DIAGNOdent device was used throughout the study, and the three examiners performed the measurements on all subjects. The measurement time was standardised to around 10 seconds. As recommended by the manufacturer, before every measurement session the instrument was calibrated against the ceramic standard supplied and then calibrated for each individual subject by measuring at a sound site on the buccal surface.

The tooth surface was air-dried with compressed air for five seconds prior to measurement. To locate the site of the highest reading, the pre-selected measuring sites documented by digital photographs were scanned by the first examiner with DIAGNOdent using probe tip B, in accordance with the manufacturer's instructions. The DIAGNOdent reading was noted and the corresponding site was registered on the photographs (Fig 1). Following measurement by the first examiner, the second and third examiners performed DIAGNOdent readings independently, under identical conditions, taking readings at the lesion sites indicated on the photographs. After a one-week interval, the same measuring procedures were repeated by the same three observers. The observers again took independent readings of the same lesions using the photographs as guidelines. No records of DIAGNOdent readings from the first measurement session were available at the second measurement session.

DATA ANALYSIS

Assessment of Observer Agreements

Diagnostic agreement between DIAGNOdent readings performed by the first examiner and visual inspection was assessed by box plots. Inter-examiner agreement among the three examiners and intra-examiner agree

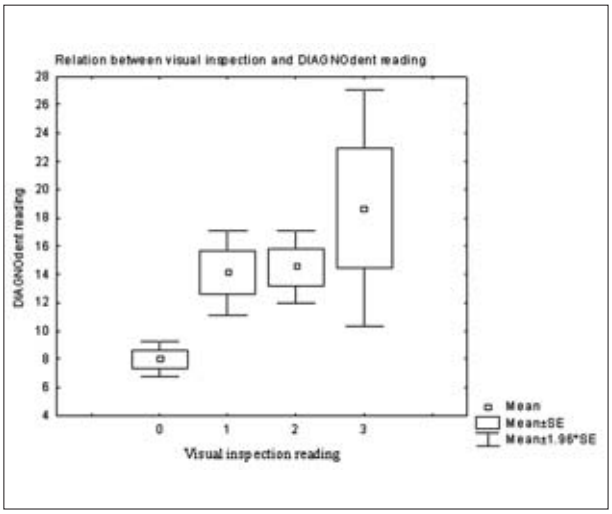

Fig 2 The relationship between the DIAGNOdent reading and lesion severity, as categorised by visual inspection

Table 1 Visual inspection criteria (modified Ekstrand criteria)

Code	Criteria
0	No or slight change in enamel translucency after pro longed air-drying.
1	Opacity (white) hardly visible on the wet surface, but distinctly visible after air-drying
2	Opacity (white) distinctly visible without air-drying.
3	Localised enamel breakdown in opaque or discolored enamel and or greyish discoloration from the underlying dentine.

Table 2 Intra-and inter-observer agreement

Intra-observer agreement		Inter-observer agreement	
1st examiner	0.91	1st time	0.69
2nd examiner	0.97	2nd time	0.82
3rd examiner	0.99	Mean value	0.75
Mean value	0.96		

ment for each observer between the two DIAGNOdent measurement sessions were analysed by intra-class correlation coefficient (ICC). This evaluates the level of agreement between and within examiners.

The relationship between visual inspection and DIAGNOdent readings were analysed by Spearman rank correlation coefficient.

RESULTS

The mean and standard error of DIAGNOdent values in different categories of visual examination score are illustrated as box plots (Fig 2). The Spearman rank correlation coefficient between the visual scores and the DIAGNOdent readings was only 0.39. The ICC values for intra-examiner reproducibility, shown in Table 2, were 0.91, 0.97 and 0.99 respectively, with a mean value of 0.96, indicating excellent intra-examiner agreement. As shown in Table 2, the ICC value for inter-examiner reproducibility for the first measurement session was 0.69 and 0.82 for the second measurement session.

DISCUSSION

The reliability of a diagnostic method is important in both clinical and epidemiological studies, because it indicates how well the method fulfils the requirement of providing consistent, standardized readings (Nyvad et al, 1999). Reliability testing also serves a secondary purpose, indicating how well observers agree within and between themselves.

In the present study, clinical intra- and inter-examiner agreement was tested for DIAGNOdent measurement of white spot lesions that had developed around bands and brackets during orthodontic treatment. In vitro studies, mostly on occlusal surfaces, have shown excellent intra-examiner agreement for DIAGNOdent (Lussi et al, 1999; Shi et al, 2000; Attrill and Ashley, 2001; Bamzahim et al, 2002; Alwas-Danowska et al, 2002; Lussi and Francescut, 2003; Kühnisch et al, 2004).

Fig 2 demonstrated mean DIAGNOdent values classified into four categories according to the visual inspection. There is a clear trend that with a higher visual score the DIAGNOdent values increases as well. However the Spearman rank correlation coefficient was only around 0.4. The capacity of a quantitative method like DIAGNOdent may be under- estimated when using a qualitative and subjective measure, visual inspection, as gold standard.

Under clinical conditions, variables are not as readily controlled as under in vitro conditions. A number of variables may adversely affect the reproducibility of the DIAGNOdent method, such as the humidity of the tooth surface, the presence of dental plaque or calculus and also staining of various kinds (Lussi et al, 1999; Shi et al, 2000). In the present study, special measures were taken to control or minimise such potential confounders, e.g. by exclusion of teeth with flu-

orosis, tetracycline staining or staining of other origin and by careful cleaning of the tooth surfaces.

In order to standardise the humidity of the teeth, the duration of the drying procedure was strictly regulated at five seconds.

The results showed excellent intra-examiner agreement: for quantification of white spot lesion on smooth surfaces the mean ICC value of 0.96 is in good agreement with a previous report by Shi et al (2001), where the ICC value was 0.94 under in vitro conditions and with 0.75 (Kappa) under in vivo conditions (Pinelli et al, 2002).

The mean ICC value for inter-examiner agreement, 0.75, was much lower. This value is in general agreement with a recent report by Aljehani et al (2004), where the ICC value was 0.80 under in vitro conditions. Moreover, there was a pronounced discrepancy in inter-examiner agreement between the first and second measurement sessions (0.69 and 0.82 respectively). This discrepancy might be attributable to such factors as examiner effect, subject effects and imperfect calibration of the device.

As with all methods involving technology, performance is determined partly by the examiner's experience in using the equipment and the technique of application. Of the three operators, one was inexperienced in the DIAGNOdent method compared with the other two operators, with only the short training period before the study. Exclusion of this examiner's results from the first evaluation of inter-observer agreement yielded ICC values of 0.92 and 0.95 for the first and second measurements respectively. The higher ICC value for the second evaluation of inter-observer agreement may be attributable to the fact that the examiner had become increasingly skilled in the technique after measuring 137 surfaces in the first round of measurement. This stresses the importance of training on a relatively high number of teeth.

In order to obtain comparable data in longitudinal studies of changes in carious lesions, the DIAGNOdent device should be calibrated frequently (Karlsson et al, 2004; Braun et al, 2005). According to the manufacturer's instructions, a baseline measurement of the system is recommended both on the calibration device attached to the probe container and on a non-carious area of the tooth. Therefore, special attention should be paid to theoretical and practical training of non-experienced examiners, including demonstration of correct calibration procedures. Meticulous cleaning of the tooth surfaces before measurements is also essential.

Although in the present study the mean inter-observer agreement attained under clinical conditions was much lower than that achieved during calibration exercises on extracted teeth, an inter-observer agreement of 0.75 may nevertheless be considered acceptable: this value is in general agreement with recent in vitro reproducibility studies on occlusal caries (Alwas-Danowska et al, 2002; Kühnisch et al, 2004) and on smooth surface caries (Pinelli et al, 2002; Aljehani et al, 2004).

The present study showed that DIAGNOdent reproducibly measured incipient smooth surface lesions in vivo, with excellent intra-examiner agreement and acceptable inter-examiner agreement.

The DIAGNOdent system may therefore be recommended for reliable assessment of white spot lesion status in patients at caries risk, such as orthodontic patients.

However, the accuracy and reliability of the system in disclosing changes in white spot lesions over time have yet to be established. To date, there are only two studies of using DIAGNOdent under clinical conditions for longitudinal monitoring of occlusal carious lesions (Anttonen et al, 2004, Sköld-Larsson et al, 2004) that indicated that it is possible to monitor lesion changes. It is concluded that for quantitative assessment of severity of white spot lesions in the clinical setting, the DIAGNOdent method shows excellent intra-observer agreement and acceptable inter-observer agreement. The readings may aid clinical decision- making with respect to management of orthodontically induced smooth surface lesions. Further studies are warranted to determine whether the method is applicable in the general practice setting for monitoring the status of white spot lesions or evaluating the effect of interventions intended to arrest or reverse lesion progression.

REFERENCES

1. Aljehani A, Tranaeus S, Forsberg CM, Angmar-Månsson B, Shi XQ. In vitro quantification of white spot enamel lesions adjacent to fixed orthodontic appliances using quantitative light-induced fluorescence and DIAGNOdent. Acta Odontol Scand 2004; 62:313-318.
2. Alwas-Danowska HM, Plasschaert AJ, Suliborski S, Verdonschot EH. Reliability and validity issues of laser fluorescence measurements in occlusal caries diagnosis. J Dent 2002;30:129-134.
3. Anttonen V, Seppä L, Hausen H. A follow-up study of the use of DIAGNOdent for monitoring fissure caries in children. Community Dent Oral Epidemiol 2004;32:312-318.
4. Anttonen V, Seppä L, Hausen H. Clinical study of the use of the laser fluorescence device DIAGNOdent for detection of occlusal caries in children. Caries Res 2003;37:17-23.
5. Attrill DC, Ashley PF. Occlusal caries detection in primary teeth. A comparison of DIAGNOdent with conventional methods. Br Dent J 2001;190:440-443.

6. Bamzahim M, Shi X-Q, Angmar-Månsson B. Occlusal caries detection and quantification by DIAGNOdent and Electronic Caries Monitor: in vitro comparison. Acta Odontol Scand 2002;60:360-364.
9. Basdra EK, Huber H, Komposch G. Fluoride release from orthodontic bonding agent alters the enamel surface and inhibits enamel demineralisation in vitro. Am J Orthod Dentofac Orthop 1996;106:466-472.
10. Boersma JG, van der Veen MH, Lagerweij MD, Bokhout B, Prahl-Andersen B.Caries prevalence measured with QLF after treatment with fixed orthodontic appliances: influencing factors. Caries Res 2005;39:41-47.
11. Braun A, Krause F, Jepsen S. The influence of the calibration mode of a laser fluorescence device on caries detection. Caries Res 2005;39:144-149.
12. Chang HS, Walsh LJ, Freer TJ.The effect of orthodontic treatment on salivary flow, pH, buffer capacity, and levels of mutans streptococci and lactobacilli.
13. Aust Orthod J 1999;15:229-234.
14. Ekstrand KR, Ricketts DN, Kidd EA. Reproducibility and accuracy of three methods for assessment of demineralization depth on the occlusal surface: an in vitro examination. Caries Res 1997;31:224-331.
15. Francescut P, Lussi A. Correlation between fissure discoloration, Diagnodent measurements, and caries depth: an in vitro study. Pediatr Dent 2003; 25: 559-564.
16. Gorelick L, Geiger A, Gwinnett AJ. Incidence of white spot formation after bonding and banding. Am J Orthod 1982;81:93-98.
17. Gorton J, Featherstone JD. In vivo inhibition of demineralization around orthodontic brackets. Am J Orthod Dentofac Orthop 2003;123:10-14.
18. Heinrich-Weltzien R, Weerheijm KL, Kühnisch J et al. Clinical evaluation of visual, radiographic, and laser fluorescence methods for detection of occlusal caries. ASDC J Dent Child 2002;69:127-132.
19. Hibst R, Gall R. Development of a diode laser-based fluorescence caries detector. Caries Res 1998;32:294.
20. Hibst R, Paulus R, Lussi A. Detection of occlusal caries by laser fluorescence: basic and clinical investigation. Med Laser Appl 2001;16:205-113.
21. Karlsson L, Angmar-Månsson B, Tranaeus S. Infrared fluorescence measurements – the influence of calibration frequency on longitudinal in vitro measurements with KaVo DIAGNOdent. Acta Stomatologica Naissi 2004;45:187-197.
22. Kühnisch J, Ziehe A, Brandstadt A, Heinrich-Weltzien R. An in vitro study of the reliability of DIAGNOdent measurements. J Oral Rehabil 2004;31: 895-899.
23. Lundström F, Krasse B. Streptococcus mutans and lactobacilli frequency in orthodontic patients: the effect of chlorhexidine treatments. Eur J Orthod 1987a;9:109-116.
24. Lundström F, Krasse B. Caries incidence in orthodontic patients with high levels of streptococcus mutans. Eur J Orthod 1987b;9:117-121.
25. Lussi A, Francescut P. Performance of conventional and new methods for the detection of occlusal caries in deciduous teeth. Caries Res 2003;37:2-7.
26. Lussi A, Imwinkelried S, Pitts N, Longbottom C, Reich E. Performance and reproducibility of a laser fluorescence system for detection of occlusal caries in vitro. Caries Res 1999;33:261-266.
27. Lussi A, Megert B, Longbottom C, Reich E, Francescut P. Clinical performance of a laser fluorescence device for detection of occlusal caries lesions. Eur J Oral Sci 2001;109:14-19.
28. Nyvad B, Machiulskiene V, Baelum V. Reliability of a new caries diagnostic system differentiating between active and inactive caries lesions. Caries Res 1999;33:252-260.
29. Øgaard B, Rölla G, Arends J. Orthodontic appliances and enamel demineralization. Part 1. Lesion development. Am J Orthod Dentofac Orthop 1988;94:68-73.
30. Pinelli C, Campos Serra M, de Castro Monteiro Loffredo L. Validity and reproducibility of a laser fluorescence system for detecting the activity of white-spot lesions on free smooth surfaces in vivo. Caries Res 2002; 36:19-24.
31. Reis A, Zach VL Jr, de Lima AC, de Lima Navarro MF, Grande RH. Occlusal caries detection: a comparison of DIAGNOdent and two conventional diagnostic methods. J Clin Dent 2004;15:76-82.
32. Shi X-Q, Tranaeus S, Angmar-Månsson B. Validation of DIAGNOdent for quantification of smooth-surface caries: an in vitro study. Acta Odontol Scand 2001;59:74-78.
33. Shi X-Q, Welander U, Angmar-Månsson B. Occlusal caries detection with KaVo DIAGNOdent and Radiographic examination. An in vitro comparison. Caries Res 2000;34:151-58.
34. Sköld-Larsson K, Fornell AC, Lussi A, Twetman S. Effect of topical applications of a chlorhexidine/thymol-containing varnish on fissure caries assessed by laser fluorescence. Acta Odontol Scand 2004;62:339-342.
35. Staudt CB, Lussi A, Jacquet J, Kiliaridis S. White spot lesions around brackets: in vitro detection by laser fluorescence. Eur J Oral Sci 2004;112:237-243.
36. Tranaeus S, Lindgren L-E, Karlsson L, Angmar-Månsson B. In vivo validity and reliability of IR fluorescence measurements for caries detection and quantification. Swed Dent J 2004;2:173-182.