CORRELATION BETWEEN LASER FLUORESCENCE READINGS AND VOLUME OF TOOTH PREPARATION IN INCIPIENT OCCLUSAL CARIES *IN VITRO*

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ABSTRACT

EDUARDO S. GHANAME: Correlation Between Laser Fluorescence Readings and Volume of Tooth Preparation in Incipient Occlusal Caries *In Vitro*

(Under the direction of André Ritter)

This study evaluated the correlation between laser fluorescence readings and the extent of carious tooth structure as measured by the volume of tooth preparation *in vitro*. One hundred and three permanent molars and premolars containing incipient occlusal caries were selected. DIAGNOdent and QLF readings were obtained according to manufacturer instructions. Caries was removed with ¼ round burs in high speed. The amount of uncured composite needed to fill the prepared cavity was used to calculate the volume of tooth preparation. The Pearson correlation for preparation volume and maximum DIAGNOdent reading and QLF measurements was 0.285 and 0.399 respectively. Sensitivity and specificity of DIAGNOdent was .83 and .60 and .66 and .73 for the cut-off values of 20 and 30 respectively. Within the limitations of this study, it is possible to conclude that laser fluorescence measured with DIAGNOdent and QLF does not appear to correlate well with tooth preparation volume.

DEDICATION

In memory of Dr. Deroci de Carvalho, Mr. Jose Medeiros Silveira, and Mrs. Liberty Voulo Silveira.

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INTRODUCTION

Successful management of dental carious lesions requires an accurate detection of the presence, dimension, and activity status of the lesion.[1] Currently, common methods used by dental practitioners to detect carious lesions are based on visual and tactile examinations, along with radiographic assessments.[2, 3] However, since visual, tactile, and radiographic examinations are highly dependent on subjective interpretation, discrepancies among dentists' diagnoses tend to be frequent,[4, 5] especially when diagnosing incipient carious lesions.

It would be clearly beneficial for clinicians to have objective methods for caries diagnosis and carious lesion detection. Several innovative methods for detecting carious lesions have recently become available, including measurements of the scattering of light, fibre optic transillumination, ultrasound imaging, electrical conductance measurements, and laser fluorescence.[6] DIAGNOdent (Kavo America, Lake Zurich, Illinois) and Quantitative Light-induced Fluorescence (OMINII Oral Pharmaceuticals, West Palm Beach, Florida), are laser fluorescence devices intended for detection of incipient occlusal and smooth surface caries.[7] Manufacturers promote the devices as an objective diagnostic aid, developed to help clinicians detect caries at the earliest possible stage. However, although both DIAGNOdent and QLF have been validated in *in vitro*[8, 9, 10] and *in vivo* studies,[11, 12] there is no scientific evidence to support a direct correlation between laser fluorescence readings and the extent of carious lesions.

Studies have evaluated the correlation between laser fluorescence readings and depth of carious lesions.[13, 14, 15, 16, 2,] Although depth measurements are extremely important for clinical judgement, volume measurement may be more representative of the lesion extension because it offers a multi-dimensional perspective. Data demonstrating a correlation between laser fluorescence and volume of tooth preparations on incipient occlusal carious lesions are lacking.

The aim of this study was to evaluate the correlation between laser fluorescence readings (as measured by DIAGNOdent and QLF) and the extent of carious tooth structure as measured by the volume of tooth preparation *in vitro*. The study examines the null hypothesis that laser fluorescence readings have no correlation with the amount of tooth structure removed during tooth preparation in incipient occlusal caries *in vitro*.

A second aim of the study was to evaluate the association between the volume of tooth preparation and visual and radiographic examinations of incipient occlusal carious lesions. The study also examines the null hypothesis that visual examination and radiographic assessment have no association with the amount of tooth structure removed during tooth preparation in incipient occlusal caries *in vitro*

In addition, the study aimed to determine the sensitivity and specificity of visual examination, radiographic assessment, and DIAGNOdent for identifying lesions in dentin as well as inter and intra-observer reliability of visual examination and radiographic assessment.

LITERATURE REVIEW

Dental caries

Caries is an infectious bacterial-mediated disease process that affects teeth. It has a multifactorial etiology and its progression is related to an intricate relationship between acid-producing bacteria, dietary fermentable carbohydrates, host factors, and time.[17, 18]

Dental caries is not a recent phenomenon. Signs of the disease are evident in human skulls dated from approximately a million years ago.[19] Furthermore, reports from as early as 5000 BC describe the existence of tooth worms, which were alleged to cause this disease.[20, 21] Even though dental caries has affected humans since the Neolithic era, the incidence of the disease did not significantly rise until the medieval age. This sharp increase has been associated with the rise in the consumption of carbohydrates.

Carbohydrates are one of the main types of nutrients that the human body uses as source of energy. They are classified as simple (mono and disaccharides) and complex (oligo and polysaccharides). After consumption, carbohydrates are an important factor in the dental caries process.[22] They are metabolized by endogenous microorganisms such as *Streptococcus mutans* and *Streptococcus sobrinus*, resulting in the production of weak organic acids. As a consequence, local pH value falls below a crucial value resulting in the demineralization of the tooth structure.[23, 24]

This demineralization is often reversed by the uptake of minerals such as calcium and phosphate from the host's saliva; however, if the demineralization is not reversed, and continuous diffusion of minerals persists, a distinct tooth cavitation may occur.[25] Clinically, cavitation is extremely relevant since fully demineralized enamel will not regenerate. This deterioration will allow access of larger particles such as bacteria; accordingly, restorative intervention is often advised.[26, 27]

Cavitation, nonetheless, is only a sign of a rather advanced stage of the disease.[28] Dental caries is a continuous process with numerous stages.[23] The main objective of contemporary clinical practice is to diagnose dental caries at the earliest possible stage to allow the clinician the opportunity to implement effective preventive strategies that involve controlling the disease by avoiding demineralization and encouraging remineralisation of the tooth structure.[29, 30]

Dental caries diagnosis

Ideal diagnostic methods should be able to accurately identify the numerous stages of the caries process. Furthermore, these methods should be valid, precise, objective, reproducible, simple to use, and allow for characterization and longitudinal monitoring of a lesion.[31, 32, 33]

Clinicians may obtain four possible outcomes when using a diagnostic method: true positive (TP), false positive (FP), true negative (TN) or a false negative (FN). Therefore, they should be concerned in knowing the probability that a disease is truly present or absent when the diagnostic method used yields a positive or a negative

result.[34, 35] A 2x2 table depicting the relationship of the four outcomes is then created (Table 1) and sensitivity and specificity values are estimated. Sensitivity, calculated as TP/ TP+FN, is the ability of a diagnostic test to identify the presence of disease. Specificity, calculated as TN/ FP+TN, is the ability of a diagnostic test to correctly identify the absence of disease.

The accurate detection of dental caries is essential for treating the disease successfully. While diagnostic methods that yield an elevated number of false positive findings (low specificity) may lead to unnecessary restorative intervention, a high number of false negative findings (low sensitivity) may leave active disease unmanaged.

Visual examination

Currently, the most common method used to detect carious lesions is based on visual examination of the tooth structure, with or without the aid of tactile information, and visual assessment of dental radiographs.[36, 37] The use of visual information on the diagnosis of dental caries has been employed for decades with little modification. Improved illumination and the use of magnifying lenses, from simple loupes to more complex surgical microscopes, have been used for technique refinements.[38] However, **v**isual examination is highly dependent on subjective interpretation and discrepancies among dentists' diagnoses tend to be frequent, particularly for incipient carious lesions.[39, 5]

Lussi[40] compared the accuracy of several common methods for the diagnosis of occlusal caries. The author examined 63 human teeth without restorations and without

macroscopic cavitations, but with varying amounts of fissure discoloration and decalcification, and reported that approximately 55% of sound teeth were misclassified as being decayed.

Bader and colleagues[41] carried out a systematic literature review of the performance of traditional methods for identifying carious lesions in 2002. The sensitivity values of visual examinations of occlusal caries reported in the reviewed studies exhibited considerable variation, ranging from .12 to .95 with 19 scores falling below .80 and only five above.

Specificity values ranged from .41 to 1.00 with only eight scores falling below .80 and 16 scores above. In short, clinicians are more prone to fail to diagnose dental caries on occlusal surfaces then to misclassify healthy occlusal surfaces as decayed. Therefore, efforts have to be directed to ensure higher sensitivity values to enhance diagnosis based on visual examinations.

Several attempts have been made to increase sensitivity. Ekstrand[42] described comprehensive visual criteria used to assess the depth and activity of occlusal carious lesions. The criteria codes range from zero ("no or slight changes in enamel translucency after prolonged air drying") to four ("cavitation in opaque or discoloured enamel exposing the dentin beneath"). These criteria are based on the premise that it was possible to visually delineate the various stages of the dental caries process, to distinguish between active and inactive occlusal lesions and to predict the depth of the lesion.[43]

Recently, an *Ad Hoc* group proposed a new visual classification system, the International Caries Detection and Assessment System (ICDAS).[44] The ICDAS criteria were created with the objective of addressing the incompatibility of terminology, criteria

and grading systems currently used in the fields of caries epidemiology, clinical caries research, and clinical caries management.

The ICDAS criteria protocol is a comprehensive system that is meant to be unifying and provide a standard framework for research comparison. The ICDAS uses predominantly visual criteria used to evaluate the characteristics of clean, dry teeth, recording both enamel and dentin caries. It can be used on coronal and root surface caries as well as caries adjacent to restorations and sealants.

The ICDAS criteria for coronal primary caries are divided according to the type of tooth surface: pits and fissures, smooth surfaces (mesial and distal with or without adjacent tooth present) and free smooth surface (bucal and lingual). The criteria codes for pits and fissure caries range from zero ("sound tooth") to six ("extensive distinct cavity with visible dentin ") depending on the severity of the lesion (Table 2).

Visual/tactile examination

Dental explorers have been used for decades and have been considered as an important adjunct to visual examinations.[45, 46, 47] As depicted by Radike,[48] a suspicious surface may be considered carious when a sharp explorer "catches" or resists withdraw after insertion with moderate to firm pressure; however, visual examination with the aid of tactile information also is highly dependent on subjective interpretation. A dental explorer that "catches" during clinical examination is not necessarily indicative of dental caries. While deep occlusal pits and fissures may physically trap dental explorers yielding

false positives, narrow occlusal anatomy may prevent explorer access to the base of pits and fissures and yield false negatives. [27, 49]

Lussi[50] evaluated the accuracy of the dental explorer in diagnosing pit and fissure caries reporting that the sensitivity of the dental explorer was reported at .62 and the specificity at .84. The author reported no statistically significant difference in diagnostic accuracy between explorer and visual technique, concluding that the use of a dental explorer did not improve the accuracy of the diagnosis of pit and fissure caries when compared to that of a visual inspection alone.

In a previously mentioned systematic literature review of the performance of traditional methods for identifying carious lesions, Bader and colleagues[41] reported that the variation in sensitivity and specificity of a combined visual-tactile method was very similar to that seen for the visual method alone. The sensitivity of visual-tactile examinations of occlusal surfaces carious lesions ranged from .14 to .61 with three scores falling below .50 and only one score above. The specificity scores varied from .87 to 1.00 with one score falling below .90 and three scores above. Thus, similarly to visual examination alone, clinicians using visual/tactile methods are more prone to not diagnose dental caries present on occlusal surfaces than to misclassify healthy occlusal surfaces as being decayed.

Radiographic assessment

One of the greatest achievements in the medical field was the discovery of x-rays by Wilhelm Conrad Roentgen in 1895.[51] While experimenting with cathode rays in a glass vacuum tube, Roentgen noticed that the dark paper coating the glass tube exhibited fluorescence when the electron beam was turned on. He also noticed that the fluorescence increased as the dark paper was moved closer to the tube and lessened when the beam tube was off. [52, 53]

Radiographs have been used as diagnostic aids in dentistry ever since Roentgen's discovery.[54] Radiographic assessment of dental caries is based mainly on the premise that the mineral content of teeth decreases as the caries process develops. Consequently, as the x-rays are projected into the tooth, the radiographic density as recorded on the image receptor is greater (i.e., darker) and may be identified by the clinician as a sign of the lesion. Thus radiographic assessments depend on visual information and also are highly dependent on subjective interpretation.

Bader and colleagues[41] also have included studies of radiographic methods for detection of carious lesions in the previously mentioned systematic review. Similar to visual and visual-tactile examinations, the authors found that the reviewed studies reported a wide range of sensitivity scores and a narrow range of specificity scores. While sensitivity ranged from .12 to .93, with 36 scores falling below .80 and only two above, specificity values ranged from .50 to 1.00, with nine scores falling below .80 and 29 at or above.

DIAGNOdent

Over the last 10 years, several innovative methods for detecting dental caries have become available. Such methods include measurements of the scattering of light, fibre optic transillumination, ultrasound imaging, electrical conductance measurements and laser fluorescence.

DIAGNOdent (Kavo America, Lake Zurich, Illinois) is a small, lightweight, battery-powered, chair-side device that measures laser fluorescence within tooth structure. The unit operates at a wavelength of 655 nm and produces a red laser light that is directed to the tooth structure by a probe. As the incident laser light is propagated into the tooth, two-way hand piece optics allows the unit to simultaneously quantify the reflected laser light energy (Figure 1).[55]

According to the manufacturer, at this specific wavelength, healthy non-carious tooth structure exhibits little or no fluorescence, resulting in low scale readings on the monitor. However, carious tooth structure exhibits degrees of fluorescence resulting in elevated scale readings on the DIAGNOdent monitor.[56] The reason for enamel fluorescence is unknown. As it interacts with teeth, light can be absorbed, reflected, scattered or transmitted. When absorbed, the interaction between light and teeth results in the emission of energy in form of electromagnetic radiation (fluorescence).[57, 58]

The level of tooth fluorescence varies once the caries process has begun. Originally, it was assumed that the loss of inorganic component during tooth demineralization was responsible for this variation. Hibst *et al*.,[59] evaluated the effect of various calcium phosphates on the fluorescence scores, suggesting that a combination of inorganic matrix and organic components such as bacteria and their metabolite were more

likely to be responsible for tooth fluorescence. The investigators also suggested that the most plausible bacteria by-product involved was porphyrins, organic compounds found commonly in animals and plants and involved in the formation of hemoglobin.[60, 61]

When DIAGNOdent is used, the probe is scanned over the suspicious surface and two different values are displayed during the test: a real-time value for the probe position ("moment") and a maximum value for the whole surface examined ("peak"). The manufacturer's instructions suggest that, in general, peak values between 0 and 14 represent sound tooth structure, while values between 15 and 20 indicate initial caries in the enamel and values greater than 21 suggest caries in dentin.[55] The therapy currently recommended by the manufacturer based on DIAGNOdent peak values is depicted on Table 3.[62]

Numerous investigations have evaluated the sensitivity and specificity of DIAGNOdent. Lussi *et al.,*[36] reported sensitivity values of .96 and specificity values of .86 for enamel caries and sensitivity values of .92 and specificity values of .86 for dentinal caries. Shi *et al*,.[63] reported very high specificity values of DIAGNOdent for smooth surface caries (.96), while Bamzahim *et al.,*[64] and Shi *et al.,*[8] reported perfect specificity values (1.00) when detecting occlusal caries with DIAGNOdent.

In 2004, Bader and Shugars[65] carried out a systematic literature review of 25 articles on performance of DIAGNOdent for caries detection. The authors found that the sensitivity of DIANOdent measurements of occlusal dentin caries ranged from .19 to .95 with four scores falling below .80 and five scores falling at or above. The specificity scores varied from .52 to 1.00, with three scores falling below .80 and six scores above. In relation to enamel caries, while sensitivity scores ranged from .38 to .95 with five

scores falling below .80 and two above, specificity scores ranged from .24 to .95 with three scores falling below .80 and four above. The authors concluded that, although DIAGNOdent was more sensitive than traditional methods, the increased probability of false positive (low specificity) results restricted the use of the device as principal diagnostic tool.

Very few studies have evaluated the relationship between DIAGNOdent values and the extent of dental caries. Ouellet *et al,* [15] reported that high reading values of DIAGNOdent do not correlate positively with the depth of carious lesion in dentin (r = 0.3809) after evaluating 100 extracted teeth. The same conclusion was substantiated by Alwas-Danowska *et al,.*[16] after assessing 49 extracted permanent molars and 45 sites at the occlusal aspect of permanent molars in 13 patients. The authors reported that the correlation coefficient between DIAGNOdent readings and depth of carious lesion was 0.49 (enamel) and 0.38 (dentin).

Lussi *et al.,*[36] evaluated the DIAGNOdent device under *in vivo* conditions. The authors used laser fluorescence readings obtained by seven general dentists on 332 occlusal surfaces, and correlated the readings with tooth preparation depth. The authors were able to establish optimal cut-offs for DIAGNOdent and advocated specific treatment procedures: no active treatment for readings between 0 and 15, preventive measures or operative treatment depending on patient caries risk for readings between 16 and 30, and preventive and operative treatment for DIAGNOdent readings 31 and above.

Recently, Hamilton *et al*.[66] have analysed the correlation between volume of tooth preparation and DIAGNOdent readings. The authors analysed 48 teeth from 25 patients

and reported that the correlation for the preparation volume and maximum DIAGNOdent measurement was only 0.191

Quantitative light–induced fluorescence (QLF)

Another diagnostic device using laser fluorescence to detect a caries lesion is the quantitative light-induced fluorescence, QLF (OMINII Oral Pharmaceuticals, West Palm Beach, Florida). Manufacturer guidelines promote the use of QLF to quantify factors such as mineral loss, caries lesion depth and size, and stain size and severity.

In the QLF method, the tooth is illuminated by a broad beam of a blue–green light from an argon ion laser.[57, 58] Subsequently, the fluorescence images are captured by an intra-oral video camera and a frame grabber. The collected data is then stored and analyzed by custom-made software (Inspektor Research Systems BV, Amsterdam, The Netherlands).[67]

Because the fluorescent radiance of the carious lesion viewed by QLF is lower than that of sound enamel, discoloured areas (white spots) appear as dark spots.[68] Three measurements are quantified by the QLF device: lesion area (A; mm^2), fluorescence loss (ΔF; %), and fluorescence loss over the lesion area (ΔQ; $\Delta F x A$; $mm^2.\%$).[69]

A strong correlation between QLF readings and the degree of demineralization of smooth surfaces have been reported. Al-Khateeb *et al.*,[70] reported a significant correlation between laser fluorescence changes and mineral loss ($r = 0.79$) after evaluating demineralization of bovine teeth. Furthermore, Hall *et al.*,[71] also have reported a

reasonable correlation between both the histological depth and mineral loss and the change in fluorescence of carious lesions (r = 0.70 and 0.83, respectively).

Few studies have evaluated the accuracy of QLF readings in detecting occlusal caries when compared to smooth surface caries; however, sensitivity and specificity values also seem to vary. For instance, while Ferreira Zandona *et al*.,[72] reported sensitivity and specificity values of .82 and .51 respectively, ten Cate *et al*,.[73] reported values of .77 and .71 and Pretty *et al*,.[74] values of .68 and .70.

METHODS AND DESIGN

Figure 2 shows the sequence of steps used in this study. One hundred and three permanent human molars and premolars with visual evidence of incipient occlusal caries were collected from dental clinics at the School of Dentistry, University of North Carolina at Chapel Hill. The teeth were gently cleaned of all soft gingival and periodontal tissues with hand instruments and mounted on specimen holders. All specimens were stored in water throughout the duration of the study. Disinfection of the specimens was avoided in order to prevent confounding effects on DIAGNOdent readings.[75]

Laser fluorescence readings

Four sets of DIAGNOdent readings were obtained per tooth according to the manufactures' specifications. First, one examiner obtained the initial two sets of readings. Subsequently, the occlusal surfaces were treated with air driven particle abrasion (prophylaxis) using PROPHYpearls, (Kavo, America, Lake Zurich, Illinois) and the same examiner obtained the remaining third and fourth sets of DIAGNOdent readings. As per manufacturer instruction, the maximum DIAGNOdent value for the whole surface examined ("peak") of each specimen was used in this study.

Two sets of QLF readings per tooth also were obtained according to the manufactures' specifications. The first set of readings was obtained before prophylaxis whereas the second set was obtained after.

Radiographic assessment

Digital radiographs of the teeth were generated. First, a digital detector (charge-coupled device CCD, Planmeca USA, Roselle, Illinois) was placed inside a cabinet x-ray system and connected to a tabletop computer (IBM, Armonk, New York). Subsequently, dental wax was placed on the top of the CCD digital detector in order to hold and stabilize the specimens. The specimens were then placed in the cabinet in such a fashion that the lingual aspect of the tooth faced the digital receptor while the buccal aspect faced the x-ray cone beam. The path of the x-ray beam was, therefore, perpendicular to the buccal side of the tooth. Tube current, voltage, and exposure time were standardized at 8mA, 70kVp, and .14 seconds, respectively. VixWin image acquisition and display software (Dentsply, Gentex Division, Des Plaines, Illinois) was used to capture and display the images. Contrast, brightness, magnification and any other image enhancement was left at examiner's preference.

The images were inspected independently by three examiners (a resident in the department of oral and maxillofacial radiology and a resident and an assistant professor in the department of operative dentistry, School of Dentistry, University of North Carolina at Chapel Hill) in order to determine (1) presence, (2) absence, or (3) "unsure about the presence" of occlusal caries in the specimen. The examination was repeated

twice to allow calculation of inter and intra-reliability values. A seven day washout period between evaluations was used. Although instructions were given to the examiners, no calibration session was performed prior to observations. The images were randomly presented to the examiners during evaluations to reduce ordering bias. Furthermore, the examiners were unaware of the results of the laser fluorescence readings

Visual examination

The teeth were independently evaluated and scored by three examiners (two residents and an associate professor in the department of operative dentistry, School of Dentistry, University of North Carolina at Chapel Hill) using a modified version of the ICDAS criteria for visual diagnosis of incipient occlusal caries. The modified ICDAS criteria range from code zero to code three depending on the presence or absence of carious lesion and its severity (Table 4).[76] The rationale for using a modified version of the ICDAS criteria was that this study only included teeth with suspicious incipient lesions. Therefore, codes five and six of the original ICDAS criteria (distinct cavity with visible dentin and extensive distinct cavity with visible dentin respectively) were removed. In addition, code one was eliminated in order to improve reliability and codes two and three of the original criteria became codes 1 and 2 of the modified ICDAS criteria.

The three examiners worked independently and also were unaware of the results of both laser fluorescence readings and radiographic assessments. All examinations were carried out under operatory light and the examiners were asked to dry the occlusal aspect

of each specimen for approximately five seconds prior to evaluation. The use of magnification lenses was recommended, but not required. No hand instrument (i.e., dental explores) was used.

The visual examination of the specimens was repeated seven days later by the same examiners in order to allow the estimation of inter and intra-reliability values. A calibration process was carried out prior to the first examination. The study protocol was briefly reviewed and the training was centered on the examination procedure as well as detection and recording of caries lesions. The process included pictures as well as extracted teeth that were representative of the criteria used for visual examination.

Code 0: Sound tooth surface

After approximately five seconds of air-drying, no evidence of caries or questionable change in enamel translucency should be present. Surfaces with developmental defects such as enamel hypoplasias, fluorosis, tooth wear (i.e., attrition, abrasion and erosion), and extrinsic or intrinsic stains are recorded as sound.

Code 1: Visual change in enamel

Evidence of (a) carious opacity (white spot lesion) and/or (b) brown carious discoloration wider than the natural fissure/fossa and not consistent with the clinical appearance of sound enamel must be observed when tooth is wet. After air-drying for

approximately five seconds, carious opacity or discoloration not consistent with the clinical appearance of sound enamel (white or brown lesion) is visible.

Code 2: Localized enamel breakdown due to caries with no visible dentin or underlying shadow

Evidence of (a) carious opacity (white spot lesion) and/or (b) brown carious discolorations wider than the natural fissure/fossa and inconsistent with the clinical appearance of sound enamel must be observed when tooth is wet. After approximately five seconds of air-drying, carious loss of tooth structure at the entrance to, or within, the pit or fissure/fossa is found; however, the dentin is not visible in the walls or base of the cavity/discontinuity.

Code 3: Underlying dark shadow from dentin with or without localized enamel breakdown

This lesion appears as a shadow of discoloured dentin 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 dentin). 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 color.

Tooth preparation

An initial impression of the occlusal aspect of the teeth was then obtained with heavy and light body impression material (Extrude heavy and light body impression material, Kerr, Orange, California) (Figure 3). The suspected incipient occlusal carious lesion was removed by using ¼ round burs in high-speed handpiece with copious air-water spray. All preparations were done under operatory light and with the aid of magnification lenses by one operator. No mechanical retention or resistance form was performed. Visual criteria with the aid of tactile information (dental explorer) were used to determine if all caries/stain had been removed.

Volume determination

The amount of tooth structure removed during preparation (the volume of the cavity) was then quantified. First, composite resin (Amelogen Plus, Ultradent, South Jordan, Utah) was placed in the tooth preparation. Care was taken to avoid internal voids and to add composite just enough to completely fill the tooth preparation. The initial occlusal impression was then repositioned on the occlusal surface to establish original form, as an occlusal index (Figure 4). The index was removed and, after the excess composite was removed, the uncured composite resin was removed from the preparation with a dental explorer and weighed on a digital scale (Mettler Toledo, Polaris Parkway, Columbus, Ohio). The tooth preparation volume was obtained by multiplying the value of the composite's final weight by its density (2.1317 g/mm^3). This process was repeated

three times and the mean value was taken as the final measure. Once the volume was obtained, the specimens were carefully evaluated under operatory light and magnifying glasses to establish if the end point of each preparation had reached dentin or not. This visual qualification of the preparation's depth allowed the construction of 2x2 frequency tables and, consequently, the calculation of sensitivity and specificity values of visual examination, radiographic assessment and laser fluorescence readings for the detection of dentinal lesions on occlusal surfaces.

Statistical analysis

The data were analysed using SAS statistical software (SAS Institute Inc., Cary, North Carolina). First, the relationship between four independent variables (visual examination, radiographic assessment, DIAGNOdent and QLF readings), and two dependent variables (volume and depth) was explored. Pearson correlation was used for continuous variables and ANOVA was used for instances where the independent variable was discrete. In the event the dependent variable was discrete, (i.e., visual examination), a t-test comparing the mean values for the continuous predictors was used.

Specific values of the independent and dependent variables were chosen for statistical analysis. Since each tooth received six scores (two readings be each of three examiners) for both visual examination and radiographic assessment, the modal value of all six observations (the value that has the largest number of observations) per tooth was used. The higher DIAGNOdent readings after prophylaxis, the mean QLF reading

(fluorescence loss (ΔF)) and the mean volume value also were chosen for the purpose of statistical analysis.

Kappa statistics was used to measure intra and inter reliability of all examiners involved in both visual and radiographic evaluation of the specimens, while specificity and sensitivity of DIAGNOdent, visual and radiographic examinations were determined from frequency tables. A significance level of 0.05 was used for all tests.[77]

RESULTS

Results are displayed on Tables 5, 6 and 7.

Laser fluorescence readings

The frequency distribution of mean DIAGNOdent values of the two readings before and after prophylaxis is depicted in Figure 5. Before prophylaxis was performed, 25% of the scores fell between 0 – 14, while 16% fell between 15 – 20, 16% fell between 21 – 30, and 43% above 30. After prophylaxis, 33% of the scores fell between 0 – 14, 11% between 15 – 20, 10% between 21 – 30, and 46% above 30.

The frequency distribution of the higher DIAGNOdent value of the two readings after prophylaxis only, the actual value chosen for statistical analysis, is illustrated on Figure 6. While 29% of the scores fell between 0 – 14, 15% fell between 15 – 20, 15% between 21 – 30, and 41% above 30.

The sensitivity and specificity for DIAGNOdent was determined for both cut-off values of 20 (initial caries lesion on dentin according to the manufacturer) and 30 (advanced carious lesion on dentin according to the manufacturer) (Tables 8 and 9).

Sensitivity and specificity of DIAGNOdent for the detection of dentinal lesions on occlusal surfaces was then calculated and identified at .83 and .60 for the cut-off value of 20 and .67 and .73 for cut-off value of 30 respectively.

In relation to the frequency distribution of QLF values (fluorescence loss (ΔF)), 60% of the scores fell below -20% before prophylaxis was performed and 68% of the scores fell below -20% after prophylaxis. Since no specific cut-offs for caries in dentin have been proposed by the manufacturer of QLF, sensitivity and specificity values were not calculated for this device.

Radiographic assessment

During the first round of assessments, the three examiners agreed on only 53 of the 103 observations (approximately 51%). Most of the agreement scores were observed for "absence" of dental caries (72%). Disagreement was noted 50 times (approximately 48%). Entirely different scores were given by the examiners only four times in 50 observations (8%). The majority of the agreement was observed between evaluators 1 and 2 (74%), while evaluators 1 and 3 agreed 68 times (66%) and evaluators 2 and 3 only 60 times (58%).

The agreement rates did not improve much during the second round of observations. The three examiners agreed 55 times out of 103 assessments (approximately 53%), and again, the great majority of the agreement scores were observed for teeth exhibiting "absence" of caries (60%).

Disagreement was found 41 times (approximately 40%) and completely different scores were given by the three examiners only twice (5%). As in the previous measurement, the majority of the agreement was observed between examiners 1 and 2 (77%). Furthermore, evaluators 1 and 3 agreed 76 times (74%) and evaluators 2 and 3 only 56 times (54%). The inter-reliability of all three examiners was considered fair to moderate. Kappa values are depicted in tables 10 and 11.

The intra-rater reliability; however, was considered moderate to good. Between first and second examinations, examiner 1 repeated the radiographic assessment score 87 times (84%), while examiner 2 repeated the same score 78 times (76%) and examiner 3 80 times (78%). Kappa values are depicted in Table 12.

Analysis of variance comparing the modal value of all six radiographic assessment scores per specimen and the volume of tooth preparation indicated a statistically significant relationship (Table 13). There was a statistically significant difference in volume between scores 0 ("absence of caries") and 1 ("presence of caries"). The mean volume detected as carious lesions by examiners was 115.53 mm^3, while the mean volume detected as sound was 27.18 mm^3 (Table 14).

Table 15 shows the modal radiographic assessment by depth. Sensitivity and specificity of radiographic assessment for the detection of dentinal lesions on occlusal surfaces also were calculated after comparing the radiographic scores and the depth of the cavity preparation (i.e., dentin or enamel) and identified as .63 and 0.86 respectively.

Visual examination

Agreement in visual evaluations appeared slightly higher when compared to radiographic assessments. The three examiners agreed on 58 of 103 observations (approximately 56%) in the first round of visual examinations. The great majority of the agreement scores were observed for code 0 (52%), followed by code 1 (21%), 3 (17%), and 2 (10%) respectively.

Disagreement was observed on 45 of 103 observations (approximately 44%). The examiners gave entirely different scores (i.e., scores 0, 1, and 2) only six times (6%) and partial agreement was observed in the remaining 39 cases (i.e., agreement between examiners 1 and 2, 1 and 3). Evaluators 1 and 2 agreed 63 times (61%) while evaluators 1 and 3 agreed 75 times (73%), which was the same percentage of agreement observed between examiners 2 and 3.

The agreement was enhanced in the second round of examinations. The three examiners agreed on 74 of 103 observations (approximately 72%); an increase of 28%. Once again, the great majority of agreement scores were observed for code 0 (42%), followed by code 1 (27%), 3 (16%), and 2 (15%) respectively. Disagreement was found 29 times (approximately 39%) and totally different scores were given by the examiners only 3 times (3%). Furthermore, evaluators 1 and 2 agreed 79 times (77%), while evaluators 1 and 3 agreed 82 times (80%) and evaluators 2 and 3, 86 times (83%). The inter-reliability of all three examiners was considered good to very good. Kappa values are depicted in tables 16 and 17.

The intra-rater reliability was also considered good to very good for all three examiners. Between first and second examinations, examiner 1 repeated the visual score 63 times (61%), while examiner 2 repeated the same score 85 times (82%) and examiner 3, 87 times (84%). Kappa values are depicted in Table 18.

Due to entry error, only 102 specimens were considered during analysis of variance and calculation of sensitivity and specificity values. Analysis of variance comparing the modal value of all six visual examination scores per specimen and the volume of tooth preparation indicated a statistically significant relationship (Table 19). A distinction between scores 1 and 3, 0 and 3, and 0 and 2 was observed. In other words, the examiners were able to clearly distinct the extremes (i.e., sound tooth from caries in dentin). However, the examiners had difficulty distinguishing more subtle differences (i.e., sound tooth from distinct visual changes on enamel) (Table 20). While the mean preparation volume of teeth classified by examiners as code 0 was 11.3mm^3, the mean volume of code 1 was 34.21 mm^3, code 2 was 89.35 mm^3, and code 3 was 149.8 mm^3.

Table 21 shows the modal value of the visual examination by lesion depth. Sensitivity and specificity of visual examination for detection of dentinal lesions on occlusal surfaces also was calculated after comparing the modified ICDAS visual scores and depth of the cavity preparation (i.e., enamel or dentin) for a cut-off between codes 2 and 3 and defined as .60 and .98 respectively. Since code 2 ("localized enamel breakdown") may arguably be a dentin lesion, sensitivity and specificity of visual examination for detection of dentinal lesions on occlusal surfaces also was calculated for a cut-off between codes 1 and 2 and defined as .97 and .94 respectively.

Volume determination

A weak, non-statistically significant correlation ($p>0.001$) was observed when comparing the highest DIAGNOdent values and volume of tooth preparation ($r = 0.285$). A higher but statistically significant correlation coefficient ($p<0.001$) was observed when comparing mean QLF reading and volume of tooth preparation ($r = 0.399$). Scatter graphics representing the relationships observed in this study are depicted in Figures 7 and 8.

DISCUSSION

Clinicians are continuously searching for the ideal diagnostic method. The thought of having an instrument that can accurately identify the various stages of the caries process and simultaneously quantify the extension of the lesion and offer ideal treatment options is extremely appealing.

Currently, the most common methods used by clinicians to diagnose dental caries are based on visual examination, a combination of visual examination and tactile information, and radiographic assessments. However, the major concern with these traditional methods is that they are highly subjective and discrepancies among clinicians' diagnoses tend to occur.

Several new methods for caries diagnosis have been introduced in the past decade that claim to be more objective, valid, precise, reproducible, and simple to use. DIAGNOdent and QLF, for instance, are laser fluorescence devices intended for an objective detection of occlusal and smooth surface caries. Both devices provide a quantification of the carious lesion by a simple numerical index. Furthermore, manufacture guidelines for the use of DIAGNOdent also offer treatment strategies according to the numbers revealed by the device during test.

However, the advent of these new diagnostic devices creates a serious clinical dilemma. Can the clinician rely solely on DIAGNOdent and QLF measurements? Do

DIAGNOdent and QLF provide a more accurate diagnosis than visual examination alone? Furthermore, can the clinician always apply their therapeutic recommendations with conviction?

The results of this study, which set out to evaluate the correlation between laser fluorescence readings (as measured by DIAGNOdent and QLF) and the volume of tooth preparation (the later being an indicative of caries), suggest a small to moderate relationship.

One hundred and three extracted teeth were used in this study. Storage solutions such as chloramine, formalin, and thymol may have significant influence on the fluorescence measured by DIAGNOdent and QLF.[75] Saliva contains a variety of electrolytes including sodium, potassium, magnesium, calcium, bicarbonate, and phosphates.[78] To preserve the presence of these electrolytes, and inhibit any influence on the measurement of fluorescence, the teeth were stored in water prior to visual and radiographic assessments and laser fluorescence measurements.

Once the diagnostic tests were performed, the suspected incipient occlusal carious lesion was removed by using ¼ round burs to provide the most conservative preparation. No mechanical retention or resistance form was done. A combination of visual-tactile criteria was used to determine if all caries/stain had been removed. While these end point criteria may be considered subjective, this is the most common method used by clinicians in the completion of caries excavation.

Following tooth preparation, the amount of tooth structure removed was quantified by using composite resin. Other methods for volume quantification were considered such as the use of dental wax, impression materials, computed tomography,

pycnometer, and water displacement. However, the last three techniques were discarded because their use in human subjects would be impractical. Additionally, volume determination with impression materials was not utilized due to technique sensitivity (i.e., presence of voids and distortion). In addition, the use of dental wax can be very cumbersome, particularly when dealing with very retentive preparations, and therefore not utilized in this study.

Volume determination with composite was completed by packing the resin into the preparation. A pre-op occlusal impression was positioned in order to establish original form. Special care was taken in order to verify the correct position of the pre-op impressions.

The lightest possible shade of the composite resin was chosen in order to facilitate the distinction between composite resin and tooth structure during excess removal. However, although the accurate distinction between composite resin and tooth structure was not difficult, the use of dyes may be recommended for easier evaluations.

Volume determination was performed three times per specimen and the mean value per specimen was used for statistical analysis. The precision of the method was considered satisfactory since the standard deviation of all specimens was very small. However, the accuracy of the method may be better evaluated after comparison with other methods such as computed tomography measurements.

Comparison with previously published results is problematic since the great majority of the studies have only evaluated the correlation between laser fluorescence readings and depth carious lesions. As previously mentioned, the reason for evaluating the correlation between laser fluorescence readings and volume instead of depth was due

to the fact that volume measurement may be more representative of lesion extension since it offers a multi-dimensional perspective.

Nevertheless, the correlation coefficient for volume preparation and laser fluorescence readings as measured by DIAGNOdent and QLF reported in this study (r = 0.228 and 0.399 respectively) were similar to the coefficient reported by Ouellet *et al,*. [15] for DIAGNOdent readings and depth of the caries (r = 0.4438) and caries in dentin (r = 0.3809). However, the coefficient was somewhat smaller than the values reported by Alwas-Danowska *et al,*.[16] who observed correlation coefficient ranging from 0.48 to 0.53.

To date, the only study that has evaluated the correlation between volume of tooth preparation and DIAGNOdent readings was published by Hamilton *et al,*.[66] The authors analysed 48 teeth from 25 patients and reported that the correlation for the preparation volume and maximum DIAGNOdent reading was only 0.191. However, the authors used a small sample size (32 teeth without cavitation) and the research design may not have been appropriate for addressing the research question. The authors used a low viscosity polyvinyl siloxane to quantify the volume of the preparations, but failed to recognize the limitations of the method such as the likelihood of voids and distortion.

The weak correlation observed in this study may indicate that the intensity of the fluorescence was not proportional to the size of the carious lesion. This result may be better explained by the inability of the DIAGNOdent and QLF to differentiate between superficial and deeper dentinal caries. [9, 10] The angulation of the DIAGNOdent tip and the possible presence of residues before and after prophylaxis also may have affected the readings.

Since no specific cut-offs for caries in dentin have been proposed by the manufacturer of QLF, sensitivity and specificity values were not calculated for this device. The sensitivity and specificity of DIAGNOdent for the detection of dentinal lesions on occlusal surfaces however, were calculated at .83 and .60 for the cut-off value of 20 ("initial caries lesion on dentin" according to the manufacturer) and .66 and .72 for cut-off value of 30 ("advanced carious lesion on dentin" also according to manufacturer).

The results were comparable to previous values reported by Lussi and Francescut[79] (0.75 and 0.68), Heinrich-Weltizien *et al.*,[14] (.84 and .70), and Angnes *et al*,.[13] (.81 and .54), Cortes *et al*,.[80] (.84 and .67), and Alwas-Danowska *et al*.,[16] (.95 and .52). However, the results of this study did not agree with the values reported by Lussi *et al.,*[36] who originally established these cut-offs for DIAGNOdent. It is interesting to note that the sensitivity of DIAGNOdent decreased when the cut-off was set at 30. This fact also may corroborate the inability of the device to accurately diagnose deeper dentinal caries.

Sensitivity and specificity of visual examination for detection of dentinal lesions on occlusal surfaces was calculated at .60 and .98 respectively. The results were similar to the values reported by Ashley *et al*,.[81] (.78 and .95), Ricketts *et al*,.[82] (.63 and .97), Verdonshot *et al*,.[83] (.48 and .89), and Wenzel *et al*,.[84] (.54 and .81).

Although the modified ICDAS criteria represented an attempt to increase sensitivity scores of visual examinations, the value calculated in this thesis was a little disappointing, and far below the value reported by Ekstrand *et al*,.[85] (.95). A plausible cause for the lower sensitivity value is the probability that the modified ICDAS may have

required more extensive examiner training and experience than what was afforded in this study.

Two calibration sessions were performed in this study. The first calibration consisted of pictures of representative samples. Subsequently, a round of visual examinations was performed. Intra-reliability scores were extremely disappointing and a second calibration meeting was scheduled.

Criteria codes were then reviewed once again and twenty-five extracted teeth representative of all four modified ICDAS criteria codes were presented to the examiners. The examiners were then asked to grade the samples and discuss the rationale behind each decision. The inter- and intra-reliability greatly increased after the second calibration meeting and was considered good to very good.

Sensitivity and specificity values of radiographic assessments for the detection of dentinal lesions on occlusal surfaces were reported in this study (.63 and .86 respectively). The results were similar to the values reported by Huysmans *et al*,.[86] (.58 and .87), Ricketts *et al*,.[87] (.62 and .76), Verdonshot *et al*.,[83] (.61 and .79), and Wenzel *et al*,.[88] (.64 and .94). Although examiner bias may have occurred because the evaluators knew the teeth had suspicious incipient occlusal caries, the results suggest that the examiners were more prone to fail to notice dental caries present on occlusal surfaces than to misclassify healthy occlusal surfaces as being decayed.

Clinical implications

A new diagnostic method must perform significantly better than the current gold standard in order to be accepted. The evaluation of the correlation between laser fluorescence readings and volume of incipient carious lesions indicated a very weak relationship. In addition, the comparisons of specificity and sensitivity among DIAGNOdent, visual examination, and radiographic assessment did not reveal a substantial difference among the methods. Therefore, although new technologies such as DIAGNOdent and QLF may appear to be an objective way to identify dental caries, the clinician cannot base his clinical judgement and treatment decision solely on one diagnostic method or another.

Future research

The accuracy and precision of the method used in this study should be further investigated. Thus, volume determination using composite resin should be assessed by different evaluators and compared with other methods such as computed tomography. Furthermore, in vivo assessment of diagnostic performance and longitudinal examination of the correlation between variation in DIAGNOdent readings and caries extension should be done.

CONCLUSION

Within the limitations of this study, it is possible to conclude that laser fluorescence measured with DIAGNOdent and QLF does not appear to correlate well with caries extension. In other words, higher DIAGNOdent readings may not necessarily represent increasingly advanced caries into dentin as claimed by the manufacturer. Consequently, the therapy guideline proposed by the manufacturer may not be valid

Furthermore, although the sensitivity of DIAGNOdent for the detection of dentinal lesions on occlusal surfaces was higher than visual examination and radiographic assessment, the considerable likelihood of unnecessary treatment (false positive results) may preclude the use of DIAGNOdent as a primary method of caries diagnosis.

In addition, an association between visual examination and radiographic assessment and the amount of tooth structure removed during tooth preparation was observed. The examiners were able to clearly distinct extremes (i.e., sound tooth from caries in dentin). However, the examiners had difficulty distinguishing more subtle differences (i.e., sound tooth from distinct visual changes on enamel). The mean volume detected as carious lesion by examiners was 115.53mm^3.

Table 1. Representation of a 2x2 frequency table depicting the possible outcomes of the relationship between a test result and presence or absence of disease

	Disease		
Test result	Presence	Absence	Total
Positive	True positive (TP)	False Positive (FP)	TP + FP
Negative	False negative (FN)	True negative (TN)	FN + TN
Total	TP + FN	FP + TN	

Table 2. ICDAS Coronal Primary Caries Code (Pits and Fissures)

ICDAS Code	Description
0	Sound
1	First Visual Change in Enamel (seen only after prolonged air drying or restricted to within the confines of a pit or fissure)
2	Distinct Visual Change in Enamel
3	Localized Enamel Breakdown (without clinical visual signs of dentinal involvement)
4	Underlying Dark Shadow from Dentin
5	Distinct Cavity with Visible Dentin
6	Extensive Distinct Cavity with Visible Dentin

Table 3. Manufacturer recommendation of therapy according to DIAGNOdent scores

Display value	Diagnosis	Therapy
0 – 14	No caries	No special measures
15 – 20	Initial caries in enamel	Usual prophylactic measures
21 – 30	Caries in dentin	More intensive prophylaxis or restoration: indication is dependent on: Caries activity Caries risk Recall interval
30 and above	Extensive dentin caries	Restoration and more intensive prophylaxis

Table 4. Modified ICDAS criteria used in this study

Modified ICDAS Code	Summary
0	Sound
1	Distinct visual change in enamel
2	Localized enamel breakdown
3	Underlying dark shadow from dentin

(for a detailed description of each score, see text)

Table 5. Final data depicting laser fluorescence readings and caries extension

Specimen	DIAGNOdent				QLF (ΔF in %)		Volume (mm^3)			Depth*
	Before Prophy		After Prophy		Before Prophy	After Prophy	Reading 1	Reading 2	Reading 3	
1	32	33	33	30	-19	-15.9	0.02	0.0205	0.0204	1
2	6	5	6	4	-9.58	-9.75	0.0017	0.0015	0.0018	0
3	43	49	43	42	-22.4	-22.4	0.0288	0.0291	0.0294	1
4	40	55	50	55	-24.6	-20.8	0.003	0.0034	0.0032	0
5	14	17	24	17	-13.8	-12.2	0.0024	0.002	0.0026	0
6	99	99	99	99	-16.5	-16.8	0.0039	0.0031	0.0041	1
7	29	25	25	26	-19.8	-19.9	0.0121	0.0116	0.011	1
8	16	22	21	20	-15.3	-15.1	0.0079	0.0074	0.0076	0
9	12	15	13	13	-14.4	-13.8	0	0	0	0
10	9	6	9	6	-11.9	-9.55	0.003	0.0033	0.0028	0
11	17	14	15	14	-16.6	-13.8	0	0	0	0
12	78	68	75	74	-10.5	-11.6	0	0	0	0
13	13	8	8	7	-13.8	-13.7	0.0036	0.0033	0.0031	0
14	99	99	99	99	-11.8	-11.8	0.0026	0.0022	0.0018	0
15	15	16	14	13	-11.5	-11.5	0.002	0.0022	0.0017	0
16	27	27	25	26	-25	-25	0.1462	0.147	0.1471	1
17	16	14	14	14	-20.5	-20	0.0251	0.0256	0.0249	1
18	24	43	53	56	-16.2	-12.8	0.003	0.0042	0.0037	0
19	43	54	73	76	-32.6	-28.9	0.0063	0.0065	0.0057	0
20	69	59	53	54	-13.5	-13.5	0.0026	0.002	0.0023	0
21	43	42	7	5	-23.1	-11.7	0	0	0	0
22	33	32	18	15	-13.5	-13.3	0	0	0	0
23	17	35	31	32	-24.3	-22.1	0.0235	0.0236	0.0239	1
24	31	40	40	41	-31.4	-24.8	0.0048	0.004	0.0039	0

* 0 = preparation ending in enamel; 1 – preparation ending in dentin

Table 5, Continued

Specimen	DIAGNOdent				QLF (ΔF in %)		Volume (mm^3)			Depth*
	Before Prophy		After Prophy		Before Prophy	After Prophy	Reading 1	Reading 2	Reading 3	
25	17	27	20	24	-16.9	-16.9	0.0019	0.0023	0.0026	0
26	27	28	66	68	-37.3	-37.3	0.032	0.0317	0.0317	1
27	99	99	54	56	-20.1	-19.7	0.0097	0.0095	0.009	1
28	24	23	14	13	-18.5	-14.7	0.0022	0.0018	0.0015	0
29	27	26	22	39	-17.3	-16.7	0.01	0.011	0.0092	0
30	22	34	50	52	-34	-19.4	0.0048	0.0041	0.0046	0
31	10	20	13	11	-10.8	-12.2	0.0029	0.002	0.0028	0
32	55	44	72	68	-26.5	-31.7	0.0259	0.0262	0.026	1
33	74	72	41	41	-9.14	-10.3	0	0	0	0
34	16	17	19	17	-27.8	-9.65	0.0061	0.006	0.0056	0
35	11	18	25	26	-16.9	-17.2	0.0046	0.0044	0.004	0
36	99	76	95	96	-24.9	-35.2	0.0396	0.04	0.0398	1
37	98	99	99	99	-29.6	-29.9	0.0361	0.036	0.0353	1
38	6	9	7	4	-7.63	-8.75	0.0035	0.003	0.0024	0
39	12	14	13	15	-15.5	-18.1	0	0	0	0
40	14	14	7	10	-14.2	-14.4	0.0059	0.0062	0.005	0
41	72	60	56	56	-22.7	-24	0.0361	0.0357	0.0354	1
42	21	28	42	40	-31	-24.7	0.0118	0.011	0.0115	1
43	13	25	3	2	-28.6	-10.2	0.0019	0.0021	0.0019	0
44	22	14	19	14	-13.1	-11.6	0	0	0	0
45	6	9	4	3	-10.1	-14.9	0	0	0	0
46	38	34	30	32	-20.1	-21.1	0.0103	0.0109	0.0099	1
47	27	21	27	33	-26.5	-32.2	0.0037	0.0028	0.0035	0
48	76	70	69	70	-18.4	-21.1	0.004	0.0032	0.0039	0
49	8	7	6	2	-13.8	-14.7	0	0	0	0

* 0 = preparation ending in enamel; 1 – preparation ending in dentin

Table 5, Continued

Specimen	DIAGNOdent				QLF (ΔF in %)		Volume (mm^3)			Depth*
	Before Prophy		After Prophy		Before Prophy	After Prophy	Reading 1	Reading 2	Reading 3	
50	26	27	23	20	-7.89	-21.4	0.0069	0.0068	0.007	0
51	12	11	8	14	-18.8	-41.3	0.0035	0.0037	0.004	0
52	54	52	63	62	-37.4	-12.2	0.0211	0.021	0.0213	1
53	32	34	37	48	-12.2	-22.8	0.0153	0.0154	0.015	1
54	13	17	12	12	-20.9	-23.6	0	0	0	0
55	20	20	17	15	-18	-11.2	0.0068	0.007	0.0071	0
56	32	47	30	28	-9.62	-10.2	0.0215	0.0219	0.021	1
57	16	16	13	15	-15.4	-17.1	0.0058	0.0051	0.006	0
58	99	79	99	99	-25.2	-11.59	0.0018	0.0017	0.0022	0
59	33	47	53	53	-28.6	-21.2	0.0029	0.0035	0.0033	0
60	29	38	29	27	-19.2	-16.9	0	0	0	0
61	32	27	56	58	-12	-28.5	0.0061	0.007	0.0066	0
62	11	27	7	9	-14.9	-13.3	0	0	0	0
63	23	34	32	30	-16.8	-21.6	0.0205	0.0209	0.0208	1
64	47	44	43	40	-16.9	-31.5	0.032	0.031	0.0313	1
65	47	41	6	13	-28.4	-17.1	0.0032	0.003	0.0035	0
66	11	11	7	7	-11.9	-7.97	0	0	0	0
67	33	43	19	25	-23.3	-24.3	0.002	0.0019	0.0023	0
68	26	24	99	99	-29.7	-21.8	0.0057	0.0061	0.0062	0
69	57	56	51	50	-20.1	-31.5	0.0358	0.0351	0.0353	1
70	5	5	6	5	-7.96	-9.87	0	0	0	0
71	67	61	61	63	-37.3	-23.8	0.0307	0.0309	0.0315	1
72	19	13	16	22	-19.5	-15.4	0.005	0.0048	0.0047	0
73	20	20	20	21	-32.3	-33.7	0.0068	0.007	0.0062	0
74	15	13	22	25	-8.01	-19.2	0.0037	0.0041	0.0042	0

* 0 = preparation ending in enamel; 1 – preparation ending in dentin

Table 5, Continued

Specimen	DIAGNOdent				QLF (ΔF in %)		Volume (mm^3)			Depth*
	Before Prophy		After Prophy		Before Prophy	After Prophy	Reading 1	Reading 2	Reading 3	
75	7	8	9	6	-22.7	-11.9	0.0014	0.001	0.0012	0
76	4	5	8	2	-17.9	-8.03	0.0051	0.0048	0.0047	0
77	67	43	55	58	-28.5	-26.8	0.0115	0.012	0.0112	0
78	12	18	11	16	-15.1	-14	0.0024	0.0026	0.0019	0
79	11	8	20	12	-9.91	-13.1	0.0064	0.006	0.0063	0
80	14	10	12	8	-9.42	-10.8	0	0	0	0
81	17	14	15	19	-22.1	-16	0.0033	0.003	0.0031	0
82	19	11	18	12	-11.7	-14.2	0.0038	0.0029	0.0035	0
83	5	4	7	5	-18.4	-15	0	0	0	0
84	48	48	53	58	-9.65	18.7	0.0055	0.0054	0.005	0
85	48	39	26	29	-13.5	-19.6	0.0051	0.0044	0.0047	0
86	8	8	6	6	-14	-12.3	0.0265	0.0269	0.0273	1
87	99	87	37	99	-11.8	-37.8	0.0565	0.0571	0.0562	1
88	20	23	19	18	-24	14.9	0.008	0.0087	0.0081	0
89	53	52	39	38	-20.3	-27.3	0.014	0.0132	0.0141	1
90	5	4	4	2	-10.6	-7.27	0	0	0	0
91	11	10	9	13	-33.1	-14.7	0.0682	0.0691	0.0689	1
92	5	4	6	5	-16.6	-9.45	0.0023	0.0019	0.0021	0
93	99	89	48	48	-28	-18.9	0.0079	0.0083	0.0086	0
94	7	5	9	6	-12	-9.42	0.0089	0.0091	0.0087	1
95	25	36	32	30	-30.4	-21.4	0.0037	0.003	0.0035	0
96	5	6	6	6	-12	-7.7	0	0	0	0
97	56	60	41	50	-26.6	-16.4	0.0119	0.0127	0.0122	0
98	51	49	50	57	-21.5	-27.6	0.0338	0.0332	0.0339	1
99	25	29	27	27	-18.1	-17	0.0242	0.0244	0.025	1

* 0 = preparation ending in enamel; 1 – preparation ending in dentin

Table 5, Continued

Specimen	DIAGNOdent				QLF (△F in %)		Volume (mm^3)			Depth*
	Before Prophy		After Prophy		Before Prophy	After Prophy	Reading 1	Reading 2	Reading 3	
100	18	26	17	20	-17	-15.6	0.003	0.0025	0.0026	0
101	74	89	96	99	-30.5	-16.6	0.0025	0.002	0.0022	0
102	11	14	13	16	-24.4	-15.8	0.021	0.0207	0.0212	1
103	4	4	6	3	-9.7	-7.19	0	0	0	0

* 0 = preparation ending in enamel; 1 – preparation ending in dentin

Table 6. Final data depicting visual and radiographic assessment and caries extension

Specimen	Visual Examination			Radiographic Assessment			Volume (mm^3)			Depth*
	Ex 1	Ex 2	Ex 3	Ex 1	Ex 2	Ex 3	Reading 1	Reading 2	Reading 3	
1	2 2	2 2	2 2	1 1	1 0	1 1	0.02	0.0205	0.0204	1
2	0 0	0 0	0 0	0 0	0 0	0 0	0.0017	0.0015	0.0018	0
3	3 3	3 3	3 3	0 0	0 1	1 1	0.0288	0.0291	0.0294	1
4	1 2	1 1	1 1	0 0	0 0	0 2	0.003	0.0034	0.0032	0
5	0 2	0 0	1 0	1 0	1 2	0 0	0.0024	0.002	0.0026	0
6	1 3	3 3	3 3	1 0	0 0	0 0	0.0039	0.0031	0.0041	1
7	2 2	2 2	2 2	0 0	0 0	0 1	0.0121	0.0116	0.011	1
8	1 1	1 1	1 1	0 0	0 0	0 0	0.0079	0.0074	0.0076	0
9	1 2	1 1	1 1	0 0	0 1	1 1	0	0	0	0
10	0 0	0 0	0 0	0 2	0 2	0 0	0.003	0.0033	0.0028	0
11	0 0	0 0	0 1	1 1	0 1	1 1	0	0	0	0
12	0 1	0 0	0 0	0 0	0 0	0 0	0	0	0	0
13	0 2	0 0	0 0	0 0	0 0	0 0	0.0036	0.0033	0.0031	0
14	0 0	0 0	0 0	0 0	0 1	0 0	0.0026	0.0022	0.0018	0
15	0 0	0 0	0 0	0 0	0 0	0 0	0.002	0.0022	0.0017	0
16	1 2	3 2	3 3	1 1	1 1	1 1	0.1462	0.147	0.1471	1
17	3 3	3 3	3 3	1 1	1 1	1 1	0.0251	0.0256	0.0249	1
18	0 2	0 0	1 1	0 1	0 1	0 1	0.003	0.0042	0.0037	0
19	0 0	2 0	0 1	1 1	2 1	2 1	0.0063	0.0065	0.0057	0
20	0 0	0 0	0 0	0 0	0 0	2 2	0.0026	0.002	0.0023	0
21	0 0	0 0	0 0	0 0	0 0	1 2	0	0	0	0
22	0 1	0 0	0 0	0 0	0 0	0 0	0	0	0	0
23	3 3	3 3	3 3	1 1	1 1	1 1	0.0235	0.0236	0.0239	1

* 0 = preparation ending in enamel; 1 – preparation ending in dentin

Table 6, Continued

Specimen	Visual Examination						Radiographic Assessment						Volume (mm^3)			Depth*
	Ex 1		Ex 2		Ex 3		Ex 1		Ex 2		Ex 3		Reading 1	Reading 2	Reading 3	
24	3	2	1	1	1	1	0	0	0	0	1	1	0.0048	0.004	0.0039	0
25	0	2	0	0	0	0	0	2	0	0	0	2	0.0019	0.0023	0.0026	0
26	3	3	3	3	3	3	1	1	1	1	1	1	0.032	0.0317	0.0317	1
27	3	2	3	2	2	2	0	0	0	0	0	0	0.0097	0.0095	0.009	1
28	0	0	0	0	0	0	0	0	1	1	0	0	0.0022	0.0018	0.0015	0
29	1	1	1	1	1	1	0	2	0	0	1	1	0.01	0.011	0.0092	0
30	1	1	1	1	1	1	0	0	0	0	1	1	0.0048	0.0041	0.0046	0
31	0	0	0	0	0	0	0	0	0	0	1	2	0.0029	0.002	0.0028	0
32	0	3	3	3	3	3	1	1	1	1	1	1	0.0259	0.0262	0.026	1
33	0	0	0	0	0	0	1	1	1	1	0	1	0	0	0	0
34	0	0	0	0	0	0	0	0	1	0	0	0	0.0061	0.006	0.0056	0
35	0	0	0	0	0	1	1	1	0	1	1	1	0.0046	0.0044	0.004	0
36	3	3	3	3	3	3	1	1	1	1	1	1	0.0396	0.04	0.0398	1
37	3	3	3	3	3	3	1	1	1	1	1	1	0.0361	0.036	0.0353	1
38	0	0	0	0	0	0	0	2	1	0	0	2	0.0035	0.003	0.0024	0
39	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	2	2	2	2	2	2	0	2	0	0	2	1	0.0059	0.0062	0.005	0
41	3	3	3	3	3	3	1	1	1	1	1	1	0.0361	0.0357	0.0354	1
42	3	2	3	3	1	2	1	1	1	1	1	1	0.0118	0.011	0.0115	1
43	0	0	0	0	0	0	0	0	0	0	0	0	0.0019	0.0021	0.0019	0
44	0	0	0	0	0	0	0	0	2	0	0	2	0	0	0	0
45	0	0	0	0	0	0	1	1	1	0	1	1	0	0	0	0
46	1	2	2	2	2	2	0	1	1	1	1	1	0.0103	0.0109	0.0099	1
47	1	1	1	1	1	1	0	0	1	1	2	0	0.0037	0.0028	0.0035	0
48	1	2	0	0	1	1	0	0	0	0	2	2	0.004	0.0032	0.0039	0

* 0 = preparation ending in enamel; 1 – preparation ending in dentin

Table 6, Continued

Specimen	Visual Examination						Radiographic Assessment						Volume (mm^3)			Depth*
	Ex 1		Ex 2		Ex 3		Ex 1		Ex 2		Ex 3		Reading 1	Reading 1	Reading 1	
49	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
50	1	1	1	1	2	2	0	0	1	1	0	0	0.0069	0.0068	0.007	0
51	0	0	0	0	0	0	0	0	0	0	0	0	0.0035	0.0037	0.004	0
52	1	3	3	1	3	3	1	1	0	0	0	1	0.0211	0.021	0.0213	1
53	0	2	2	0	1	2	0	0	0	0	1	2	0.0153	0.0154	0.015	1
54	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0
55	0	0	0	1	1	1	1	0	0	0	0	0	0.0068	0.007	0.0071	0
56	2	2	3	2	3	3	0	1	2	1	1	1	0.0215	0.0219	0.021	1
57	2	2	2	1	1	1	0	0	1	0	0	0	0.0058	0.0051	0.006	0
58	0	3	3	0	3	0	1	1	0	1	1	1	0.0018	0.0017	0.0022	0
59	0	2	0	0	2	0	0	0	0	0	0	1	0.0029	0.0035	0.0033	0
60	0	3	0	0	2	2	0	1	0	0	1	1	0	0	0	0
61	1	0	1	1	0	1	1	1	1	1	1	1	0.0061	0.007	0.0066	0
62	0	0	0	0	0	0	1	1	0	0	1	1	0	0	0	0
63	3	2	3	3	2	3	0	0	0	0	1	1	0.0205	0.0209	0.0208	1
64	2	2	3	2	2	2	1	1	2	1	1	1	0.032	0.031	0.0313	1
65	0	0	0	0	0	0	0	0	0	0	2	1	0.0032	0.003	0.0035	0
66	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
67	2	2	1	1	1	1	0	0	0	0	0	0	0.002	0.0019	0.0023	0
68	1	2	2	2	2	2	0	0	0	0	0	0	0.0057	0.0061	0.0062	0
69	3	2	3	3	2	2	1	1	1	1	1	1	0.0358	0.0351	0.0353	1
70	0	1	0	1	1	1	0	0	0	0	0	2	0	0	0	0
71	1	2	2	2	2	2	1	1	0	0	1	1	0.0307	0.0309	0.0315	1
72	0	0	0	0	1	1	0	0	0	0	0	0	0.005	0.0048	0.0047	0
73	2	3	3	3	3	3	1	1	0	0	0	0	0.0068	0.007	0.0062	0

* 0 = preparation ending in enamel; 1 – preparation ending in dentin

Table 5, Continued

Specimen	Visual Examination						Radiographic Assessment						Volume (mm^3)			Depth*
	Ex 1		Ex 2		Ex 3		Ex 1		Ex 2		Ex 3		Reading 1	Reading 1	Reading 1	
74	0	0	0	0	0	0	1	1	1	1	1	1	0.0037	0.0041	0.0042	0
75	0	3	0	0	3	0	0	0	1	0	0	0	0.0014	0.001	0.0012	0
76	0	0	0	0	0	0	0	0	0	0	0	0	0.0051	0.0048	0.0047	0
77	0	0	0	0	0	0	0	0	0	0	0	0	0.0115	0.012	0.0112	0
78	0	0	0	0	0	0	0	0	0	0	0	0	0.0024	0.0026	0.0019	0
79	0	0	0	0	0	0	1	0	0	0	0	0	0.0064	0.006	0.0063	0
80	0	2	0	0	1	0	0	0	0	0	1	0	0	0	0	0
81	0	2	0	0	1	1	0	0	0	0	0	0	0.0033	0.003	0.0031	0
82	0	1	0	1	1	1	1	1	0	0	1	1	0.0038	0.0029	0.0035	0
83	0	2	0	1	1	1	0	0	0	0	0	0	0	0	0	0
84	1	1	1	1	0	1	0	0	0	0	0	0	0.0055	0.0054	0.005	0
85	0	1	1	1	1	1	0	0	0	0	1	1	0.0051	0.0044	0.0047	0
86	1	2	2	2	2	2	0	0	1	0	2	2	0.0265	0.0269	0.0273	1
87	3	3	3	3	3	3	0	1	0	1	1	1	0.0565	0.0571	0.0562	1
88	1	1	1	1	1	1	0	0	0	0	0	0	0.008	0.0087	0.0081	0
89	3	3	3	3	3	2	0	0	0	0	1	2	0.014	0.0132	0.0141	1
90	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
91	1	1	1	1	1	1	1	1	0	0	1	1	0.0682	0.0691	0.0689	1
92	0	1	1	0	1	1	0	0	0	0	0	0	0.0023	0.0019	0.0021	0
93	1	1	1	1	1	1	0	0	0	0	0	0	0.0079	0.0083	0.0086	0
94	2	2	2	2	2	2	1	1	1	0	2	1	0.0089	0.0091	0.0087	1
95	2	0	1	2	1	1	0	2	0	0	0	2	0.0037	0.003	0.0035	0
96	1	1	1	1	1	1	0	1	0	0	1	1	0	0	0	0
97	2	2	2	2	2	2	0	0	0	0	0	0	0.0119	0.0127	0.0122	0
98	3	3	3	3	3	3	0	0	1	0	2	2	0.0338	0.0332	0.0339	1

* 0 = preparation ending in enamel; 1 – preparation ending in dentin

Table 6, Continued

Specimen	Visual Examination						Radiographic Assessment						Volume (mm^3)			Depth*
	Ex 1		Ex 2		Ex 3		Ex 1		Ex 2		Ex 3		Reading 1	Reading 1	Reading 1	
99	1	2	2	1	2	2	1	1	1	0	1	1	0.0242	0.0244	0.025	1
100	0	3	2	0	3	1	0	0	0	0	0	0	0.003	0.0025	0.0026	0
101	1	1	1	1	1	1	0	0	2	0	0	2	0.0025	0.002	0.0022	0
102	3	3	2	3	3	2	0	0	0	0	2	2	0.021	0.0207	0.0212	1
103	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

* 0 = preparation ending in enamel; 1 – preparation ending in dentin

Table 7. Values of the independent and dependent variables used in the analysis

Specimen	Highest DIAGNOdent score	QLF mean score	Radiographic assessment mode	Visual Examination mode	Depth*	Volume (mm^3)
1	33	-17.45	1	2	1	95.23
2	6	-9.66	0	0	0	7.97
3	43	-22.40	0	3	1	136.51
4	55	-22.70	0	1	0	15.01
5	24	-13.00	0	0	0	10.78
6	99	-16.65	0	3	1	17.35
7	26	-19.85	0	2	1	54.41
8	21	-15.20	0	1	0	35.65
9	13	-14.10	0	1	0	0.00
10	9	-10.72	1	0	0	14.07
11	15	-15.20	0	0	0	0.00
12	75	-11.05	0	0	0	0.00
13	8	-13.75	0	0	0	15.48
14	99	-11.80	0	0	0	10.32
15	14	-11.50	0	0	0	9.38
16	26	-25.00	1	3	1	688.18
17	14	-20.25	1	3	1	118.21
18	56	-14.50	0	0	0	16.88
19	76	-30.75	1	0	0	29.08
20	54	-13.50	0	0	0	10.78
21	7	-17.40	0	0	0	0.00
22	18	-13.40	0	0	0	0.00
23	32	-23.20	1	3	1	111.17
24	41	-28.10	0	1	0	19.70

* 0 = preparation ending in enamel; 1 – preparation ending in dentin

Table 7, Continued

Specimen	Highest DIAGNOdent score	QLF mean score	Radiographic assessment mode	Visual Examination mode	Depth*	Volume (mm^3)
25	24	-16.90	0	0	0	10.78
26	68	-37.30	1	3	1	149.17
27	56	-19.90	0	2	1	44.09
28	14	-16.60	0	0	0	8.44
29	39	-17.00	0	1	0	47.38
30	52	-26.70	0	1	0	21.10
31	13	-11.50	0	0	0	12.19
32	72	-29.10	1	3	1	121.96
33	41	-9.72	0	0	0	0.00
34	19	-18.72	0	0	0	27.67
35	26	-17.05	1	0	0	20.17
36	96	-30.05	1	3	1	186.70
37	99	-29.75	1	3	1	167.94
38	7	-8.19	0	0	0	14.07
39	15	-16.80	0	0	0	0.00
40	10	-14.30	0	2	0	26.73
41	56	-23.35	1	3	1	167.47
42	42	-27.85	0	3	1	53.47
43	3	-19.40	0	0	0	9.38
44	19	-12.35	0	0	0	0.00
45	4	-12.50	1	0	0	0.00
46	32	-20.60	1	2	1	48.78
47	33	-29.35	0	1	0	15.48
48	70	-19.75	0	1	0	17.35
49	6	-14.25	0	0	0	0.00

* 0 = preparation ending in enamel; 1 – preparation ending in dentin

Table 7, Continued

Specimen	Highest DIAGNOdent score	QLF mean score	Radiographic assessment mode	Visual Examination mode	Depth*	Volume (mm^3)
50	23	-14.64	0	1	0	32.36
51	14	-30.05	0	0	0	17.35
52	63	-24.80	0	3	1	98.98
53	48	-17.50	0	2	1	154.13
54	12	-22.25	0	1	0	0.00
55	17	-14.60	0	0	0	32.83
56	30	-9.91	1	1	1	100.85
57	15	-16.25	0	1	0	26.27
58	99	-18.39	1	0	0	8.91
59	53	-24.90	0	0	0	15.01
60	29	-18.05	0	0	0	0.00
61	58	-20.25	1	1	0	30.96
62	9	-14.10	1	0	0	0.00
63	32	-19.20	0	3	1	97.10
64	43	-24.20	1	2	1	147.30
65	13	-22.75	0	0	0	15.01
66	7	-9.93	0	0	0	0.00
67	25	-23.80	0	1	0	9.85
68	99	-25.75	0	2	0	28.14
69	51	-25.80	1	2	1	166.06
70	6	-8.91	0	0	0	0.00
71	63	-30.55	1	2	1	145.42
72	22	-17.45	0	0	0	22.51
73	21	-33.00	0	3	0	31.43
74	25	-13.60	1	0	0	18.76

* 0 = preparation ending in enamel; 1 – preparation ending in dentin

Table 7, Continued

Specimen	Highest DIAGNOdent score	QLF mean score	Radiographic assessment mode	Visual Examination mode	Depth*	Volume (mm^3)
75	9	-17.30	0	0	0	5.62
76	8	-12.96	0	0	0	22.98
77	58	-27.65	0	0	0	54.41
78	16	-14.55	0	0	0	10.78
79	20	-11.50	0	0	0	29.08
80	12	-10.11	0	0	0	0.00
81	19	-19.05	0	0	0	14.54
82	18	-12.95	1	1	0	15.94
83	7	-16.70	0	1	0	0.00
84	58	-14.17	0	1	0	24.86
85	29	-16.55	0	1	0	22.04
86	6	-13.15	0	2	1	126.19
87	99	-24.80	1	3	1	265.51
88	19	-19.45	0	1	0	38.93
89	39	-23.80	0	3	1	64.73
90	4	-8.93	0	0	0	0.00
91	13	-23.90	1	1	1	322.27
92	6	-13.02	0	1	0	9.85
93	48	-23.45	0	1	0	38.46
94	9	-10.71	1	2	1	41.75
95	32	-25.90	0	1	0	15.94
96	6	-9.85	0	0	0	0.00
97	50	-21.50	0	2	0	57.70
98	57	-24.55	0	3	1	157.62
99	27	-17.55	1	2	1	114.93
100	20	-16.30	0	0	0	12.66

* 0 = preparation ending in enamel; 1 – preparation ending in dentin

Table 7, Continued

Specimen	Highest DIAGNOdent score	QLF mean score	Radiographic assessment mode	Visual Examination mode	Depth*	Volume (mm^3)
101	99	-23.55	0	1	0	10.32
102	16	-20.10	0	3	1	98.51
103	6	-8.44	0	0	0	0.00

* 0 = preparation ending in enamel; 1 – preparation ending in dentin

Table 8. Frequency of DIAGNOdent reading (cut-off value of 20) by depth of tooth preparation.

DIAGNOdent reading (Cut-off – 20)	Lesion depth		Total
	In dentin	Not in dentin	
Above cut-off	25	29	54
Below cut-off	5	44	49
Total	30	73	103

Table 9. Frequency of DIAGNOdent reading (cut-off value of 30) by depth of tooth preparation.

DIAGNOdent reading (Cut-off – 30)	Lesion depth		Total
	In dentin	Not in dentin	
Above cut-off	20	20	40
Below cut-off	10	53	63
Total	30	73	103

Table 10. Kappa statistics for inter-reliability scores of all three evaluators (Radiographic assessment – First reading)

Evaluators	Value	ASE	95 % Confidence Limits	
1 and 2	0.4381	0.0950	0.2520	0.6242
1 and 3	0.3717	0.0860	0.2031	0.5404
2 and 3	0.2269	0.0785	0.0731	0.3807

Table 11. Kappa statistics for inter-reliability scores of all three evaluators (Radiographic assessment – Second reading)

Evaluators	Value	ASE	95 % Confidence Limits	
1 and 2	0.5128	0.0825	0.3511	0.6745
1 and 3	0.5631	0.0646	0.4365	0.6896
2 and 3	0.2321	0.0689	0.0970	0.2278

Table 12. Kappa statistics for inter-reliability scores of all three evaluators (Radiographic assessment)

Evaluator	Value	ASE	95 % Confidence Limits	
1	0.4861	0.0885	0.3126	0.6595
2	0.4554	0.0847	0.2893	0.6214
3	0.6329	0.0625	0.5104	0.7553

Table 13. Analysis of variance depicting the association between radiographic assessment and volume of tooth preparation

Source	Type I and III Sum of Squares	df	Mean square	F	Pr > F
Radiographic assessments	162630.3225	1	162630.3225	26.40	<.0001

Table 14. Tukey's test depicting the comparison among radiographic assessment scores

Radiographic examination mode	N	Mean
1*	29	115.53
0*	74	27.18

Comparisons significant at the 0.05 level are indicated by *.

Table 15. The modal of radiographic assessment by depth of tooth preparation

Radiographic Assessment	Lesion depth		Total
	In dentin	Not in dentin	
Above Cut-off	19	10	29
Below Cut-off	11	63	74
Total	30	73	103

Table 6. Kappa statistics for inter-reliability scores of all three evaluators (Visual examination – First reading)

Evaluators	Kappa Value	ASE	95 % Confidence Limits	
1 and 2	0.4724	0.0602	0.3545	0.5903
1 and 3	0.6588	0.0572	0.5467	0.7710
2 and 3	0.5784	0.0598	0.4613	0.6955

Table 17. Kappa statistics for inter-reliability scores of all three evaluators (Visual examination Second – Reading)

Evaluators	Value	ASE	95 % Confidence Limits	
1 and 2	0.6743	0.0574	0.5618	0.7867
1 and 3	0.7146	0.0542	0.6085	0.8208
2 and 3	0.7863	0.0491	0.6900	0.8825

Table 18. Kappa statistics. Intra-reliability scores of all three evaluators (Visual examination)

Evaluator	Value	ASE	95 % Confidence Limits	
1	0.7267	0.0549	0.6192	0.8342
2	0.6627	0.0555	0.5540	0.7714
3	0.7182	0.0535	0.6134	0.8231

Table 19. Analysis of variance depicting the association between visual examination and volume of tooth preparation

Source	Type I and III Sum of Squares	df	Mean square	F	Pr > F
Visual examination	282933.6677	3	94311.2226	18.47	<.0001

Table 20. Tukey's test depicting the comparison among visual examination scores

Visual Examination Comparison	Difference Between Means	Simultaneous 95% Confidence Limits	
3 - 2	59.75	-6.03	125.53
3 - 1	118.31	61.47	175.15*
3 - 0	137.84	86.58	189.11*
2 - 1	58.56	-3.78	120.90
2 - 0	78.09	20.79	135.39*
1 - 0	19.53	-27.24	66.30

Comparisons significant at the 0.05 level are indicated by *.

Table 21. The modal of visual examination by depth of tooth preparation

Modified ICDAS Criteria	Lesion depth		Total
	In dentin	Not in dentin	
0	0	44	44
1	1	24	25
2	11	3	14
3	18	1	19
Total	30	72	102

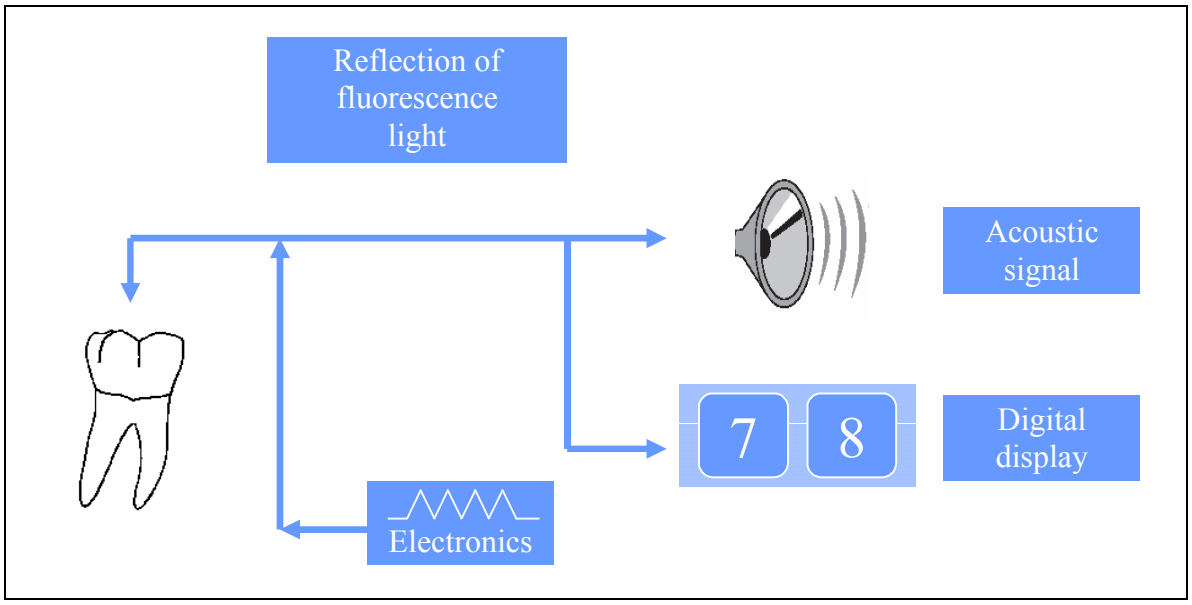

Figure 1. Operation mode of DIAGNOdent modified from manufacturer guidelines

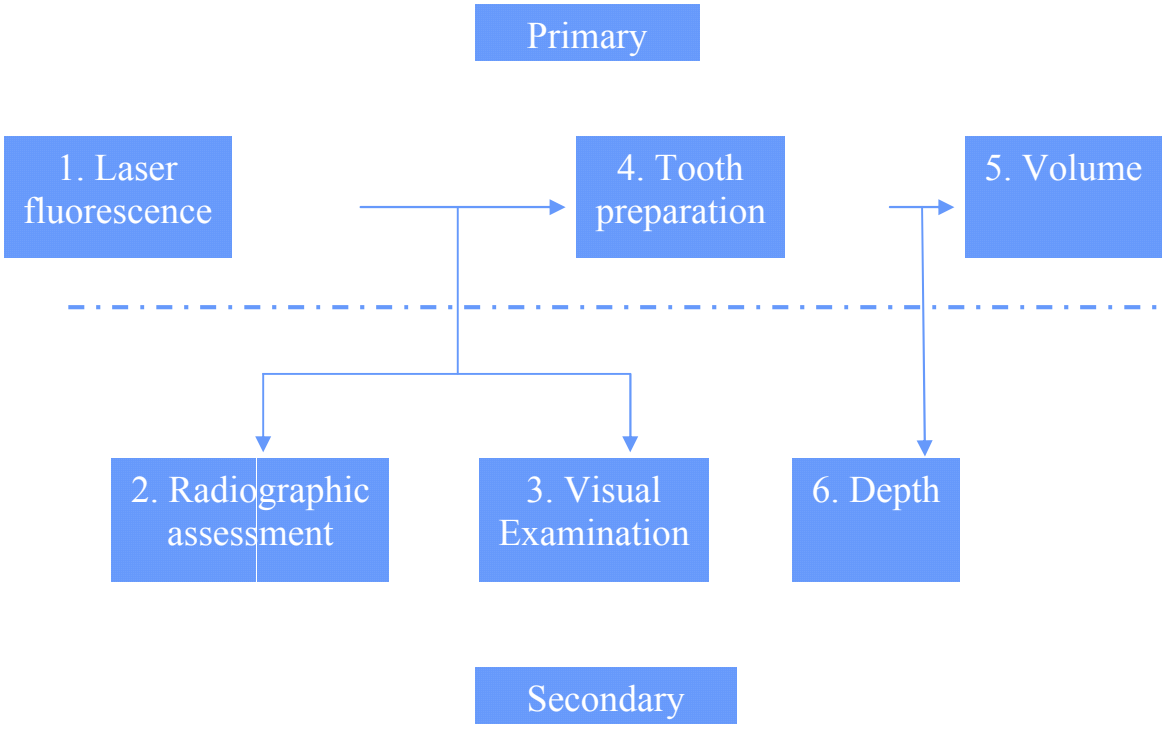

Figure 2. Depiction of the sequence of steps used in this study

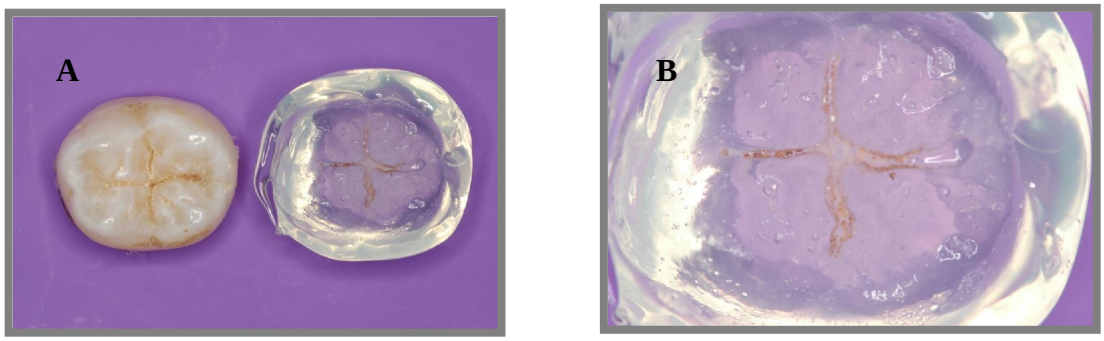

Figure 3. A. Initial impression of the occlsual aspect of a representative specimen used in this study. B. Magnified image of the pre-op occlusal impression

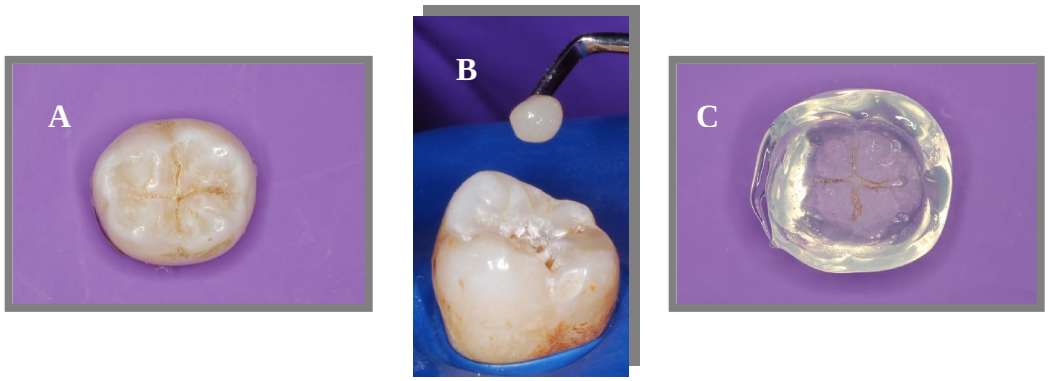

Figure 4. Volume quantification. A. Image of a sample used in this study. B. Composite resin being placed into tooth preparation. C. Pre-op occlusal impression being positioned

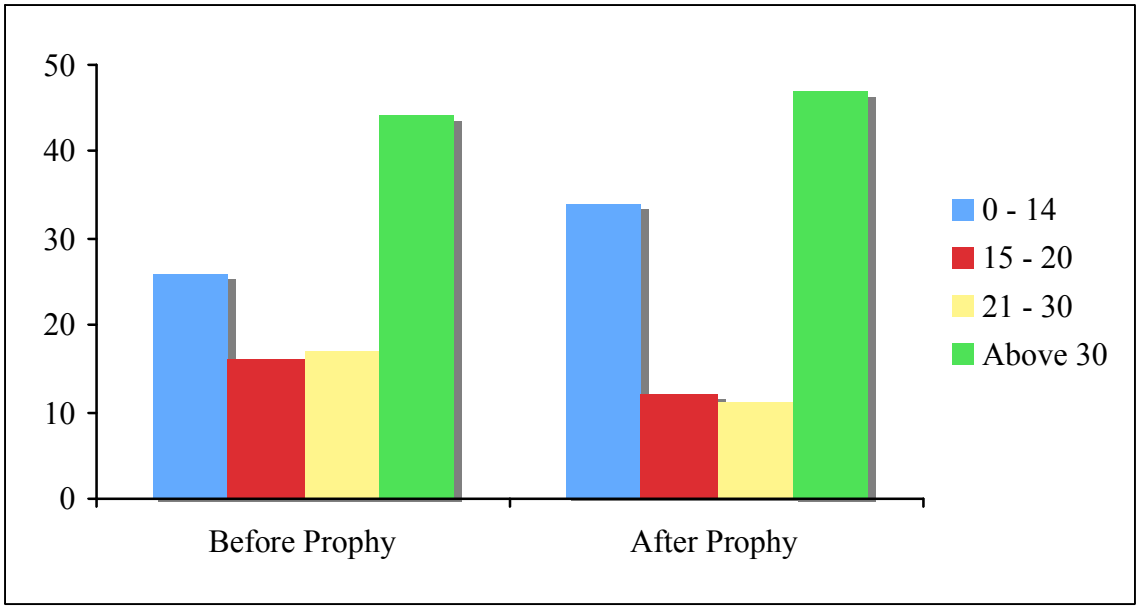

Figure 5. Frequency distribution of mean DIAGNOdent values before and after prophylaxis

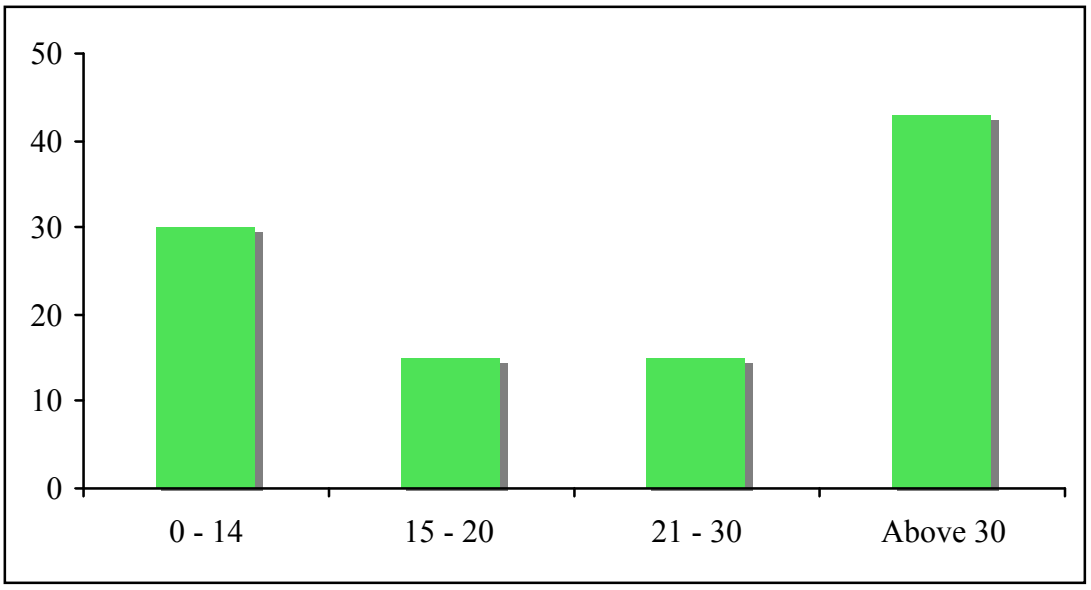

Figure 6. Frequency distribution of highest DIAGNOdent readings after prophylaxis

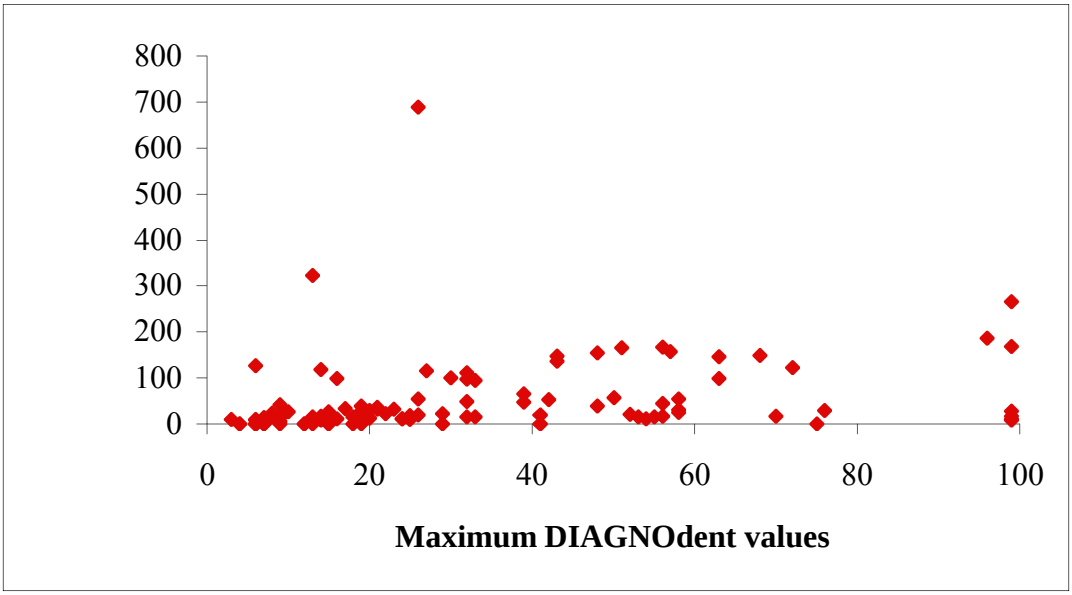

Figure 7. Correlation between maximum DIAGNOdent score and the preparation volume

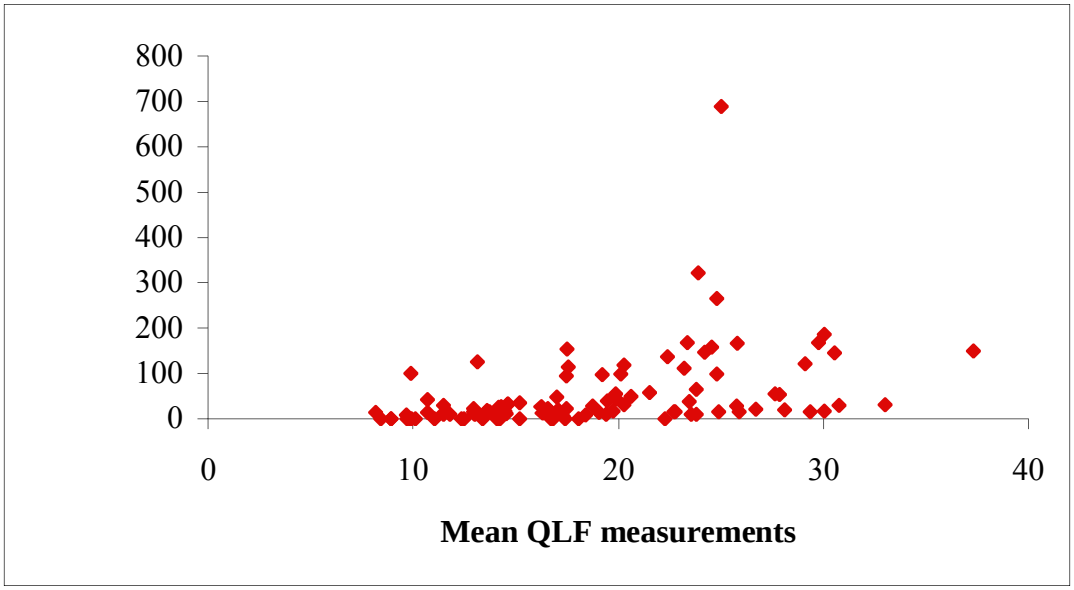

Figure 8. Correlation between mean QLF measurements and the preparation volume.

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