

Advanced methods of quantification of occlusal caries

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Chapter 2.6 was concerned with the clinical parameters used for the detection of occlusal caries. The methods mentioned there are mostly dependent on the judgement of the clinician and are, therefore, affected by operator's skills, experience, attitude and similar factors. When more definite and precise studies of the carious lesions are required, means for quantification of the lesions are necessary.

This chapter deals with methods of measuring the carious process directly numerically using specifically designed devices. The clinical relevance of published research is emphasised as not all devices are available for the practitioner, but might be in the near future.

Why need to quantify?

Quantification of data from the process of disease has long been recommended for research purposes. The clinician applying quantifying methods perceives the advantages of such preference; minimising human error, considering cut-off points rather than ranges, numerical follow-up comparisons, being reproducible, could be put in records and computers, and so on. The measuring device should be sensitive, specific and reproducible using the least number of factors that are subject to human error. Many devices have been developed in the last decade to quantify the caries process. Extensive research not only helped to prove the validity of outcomes obtained from them, but also equally important, made them user-friendlier. Not all devices are yet marketed for the daily use. Nevertheless, using these devices would have a clear impact on every days approach to caries management.

How can caries be put into numbers?

As the caries process advances in the healthy tissue, physical changes take place within the structure. The organic components of the previously mineralised tissue are altered. The organic to inorganic ratio is changed. Properties related to the organic

matter may change in regards to structural changes occurring in extreme acidic environments, chemical composition, light interactions, other sources may contribute to the organic material, and so forth. By measuring the physical property related to amount of these changes, indirectly the caries process would be judged concerning severity and activity. Experienced visual judgement has long been used accompanied by probing and radiographs as discussed earlier, However other technologies are needed to accompany these careful judgments, not replacing it, and aiding in the final decision.

Laser and light Fluorescence

This method measures the fluorescence of the natural tooth structure when induced by light irradiation to discriminate between carious and sound enamel. It is accepted that the resultant fluorescence is lower in areas of reduced mineral content, and that there is a relation between mineral loss and the radiance of the fluorescence. The term quantitative laser fluorescence (QLF)¹ had been applied to the research method of measuring induced tooth fluorescence after using a laser (488 nm range) to quantify tooth demineralisation and lesion severity. Several studies in which an argon laser light source was used to examine smooth enamel surfaces had shown a strong correlation between a decrease in fluorescence and the degree of enamel demineralisation.² QLF was best suited for longitudinal diagnosis of early lesions of the enamel on accessible smooth surfaces, and many investigations had involved the monitoring of white-spot lesions, such as those observed in orthodontic patients during treatment and after de-bracketing.³

Laboratory studies of artificial and natural decay of occlusal fissure enamel showed QLF to have better accuracy than visual examination alone or radiographic examination alone but with more false negatives. Stains and fluorescent dental materials are responsible for some of errors occur. QLF is affected to some extent by the wet or dry state of the fissure and by fissure morphology. The use of air-polishing to remove plaque improved diagnosis by QLF.⁴

Limitations for QLF system were analysed. Some reports suggested that QLF might have been limited to measurement of enamel lesions of at most several hundred

micrometres depth and could not differentiate between deep decay, hypoplasia or unusual anatomic features. It also was not designed to discriminate between enamel and dentine lesions. Furthermore, the fluorescence from dentine was not related to dentine demineralisation, so this method was not suitable for measuring dentine demineralisation.⁵ The thickness of enamel affected QLF measurements for some lesions.^{6,7} but these lesions were not affected by the thickness of sound dentine present below.⁸

Positioning of the detecting camera could also affect lesions' estimation of size. The best image was for lesions captured with the camera placed directly perpendicular to the surface measured. The apparent lesion size became smaller when captured away from this direct angle but more significantly lower if angles were deviating more than 20 degrees. These observations necessitate that positioning of the camera should be reproducible for monitoring purposes.⁹ The angle of illumination had not affected readings, while proximal lesions were best measured from the buccal surface.¹⁰ These clinical variables can explain some of the differences present between examinations but training could reduce these to become reproducible.^{11,12} Ambient light from other sources should be kept minimal when using the QLF.¹³

QLF has been repeatedly tested for monitoring different carious lesions' remineralisation and demineralisation. The following are some of these applications which are done mostly in the lab situation:

- Root lesions: Lesions were artificially produced on extracted teeth then reversed. QLF readings correlated with these lesions changes measured using radiographic analysis.¹⁴
- Early lesions in primary teeth.¹⁵⁻²¹
- Secondary caries: Detection of early secondary carious lesions was the core of recent laboratory studies. Early secondary caries and different stages of early demineralization were produced artificially or by cariogenic bacteria. QLF was able to measure these as well as compare between different materials effects in remineralising them. Glass ionomer was the best material tested for remineralising secondary lesions and followed by fluoride releasing resin

fillings. Non-fluoride releasing composite allowed for the development of larger lesions.^{22 23}

- Lesions related to orthodontic cleats and brackets.²⁴⁻²⁶
- Mouth rinses erosive ability.²⁷
- Fluoride varnish effect on early enamel lesions.²⁸
- Tooth whitening products.^{29,30}

Although there is a wide application potential for QLF, More studies are needed to apply these principles in the clinical situation, for complex occlusal caries and deep dentinal lesions.

DIAGNOdent System

It is a commercial battery-powered quantitative diode laser fluorescence device. This uses a different method than the previous one. It measures not the natural fluorescence of tooth structure but the fluorescence of the products of cariogenic bacteria. A fibre optic bundle is directed onto the occlusal surface producing light at 655-nm wavelength. A laser probe is designed for the occlusal surface to scan over the fissure area in a sweeping motion. The device then displays two values, the moment value for the probe position and a peak value recorded from the whole surface.

The diagnostic performance of DIAGNOdent was better compared with visual inspection, radiographic examination and electric caries monitoring.^{31,32;33} This conclusion had not interpreted itself into fixed cut-off points for dentine and enamel caries due to variation in protocols and validation techniques used in these studies. There was a concern about the accuracy of the device when deep dentinal lesions were measured due to its limited penetration ability, reducing its correlation with histological depth of lesions.^{34; 35} Consequently, it was strongly recommended to use DIAGNOdent in conjunction with other diagnostic tools when diagnosing dentinal lesions.³⁶⁻⁴¹

Limitations of the device to accurately designate carious activity occurs when false positive readings happen. These are readings inferring a carious lesions when there

are none. They occur around calculus, stains, cements and some composite materials.^{42,43} Suggestions of inapplicability of the values obtained from previous laboratory studies in the clinical situation were also raised. Some significant changes in DIAGNOdent readings were noticed when formalin was used to store extracted teeth, possibly by altering proteins which induce the fluorescence of carious lesions.^{44,45} Acid etching produced some change which was found to be insignificant.⁴⁶

Figure 1: Diagnosis using QLF and DIAGNOdent:

Different cleaning methods changed the DIAGNOdent readings correlation with histology (Probe cleaning, air-polishing alone, air-polishing and gentle rinsing, air polishing and the three in one syringe water spray) becoming better using the last two cleaning techniques.⁴⁷ Ozone altered DIAGNOdent readings with an immediate reduction after ozone treatment for 10 and 20 seconds.⁴⁸

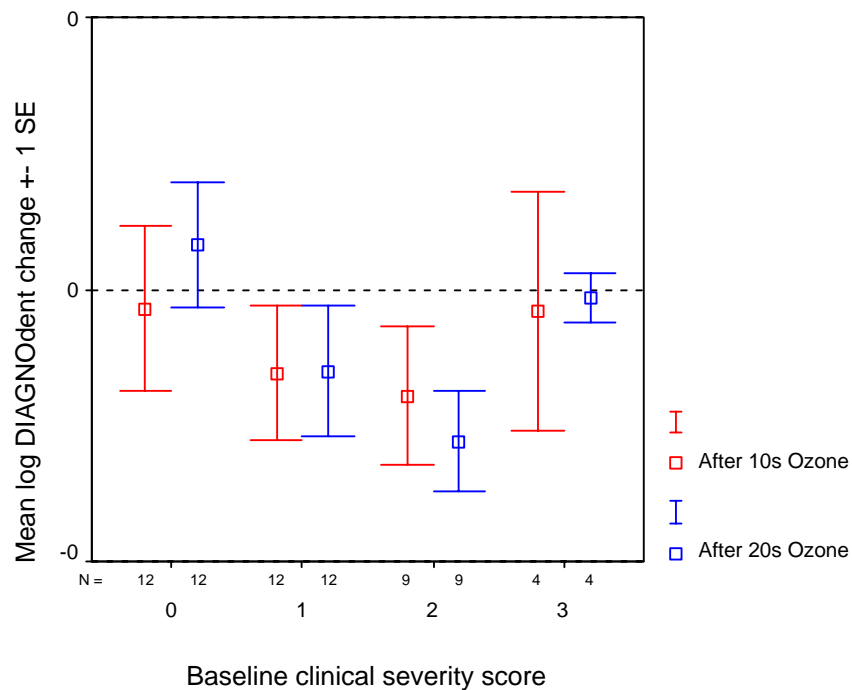


Figure 2: Mean DIAGNOdent readings change categorised by baseline Ekstrand's clinical severity scores after 10 and 20-second Ozone treatment, in-vitro.

In 199 occlusal lesions, cleaning using the air-polishing system increased the correlation of DIAGNOdent readings with the true histological depth as well as with the Ekstrand's clinical score index and the ECM readings.^{47,48} In a recent clinical study, 34 non-cavitated sound and carious pit and fissures were examined in 24 teeth. The teeth were examined within a one-week interval to test DIAGNOdent repeatability. Inclusion of sound surfaces in this test was to test of agreement between visits, which had been satisfactory at all severities (Weighed Kappa value, 0.62).⁴⁷ 388 non-cavitated pit and fissure carious lesions were examined in one visit using Ekstrand's clinical index, ECM and DIAGNOdent. The scores obtained by the different diagnostic systems used showed significant correlations.⁴⁹

The immediate effect of ozone for 10 seconds was again tested clinically in 178 lesions from 90 subjects. Another significant drop in DIAGNOdent readings was noticed related to the baseline clinical severity score.⁴⁹

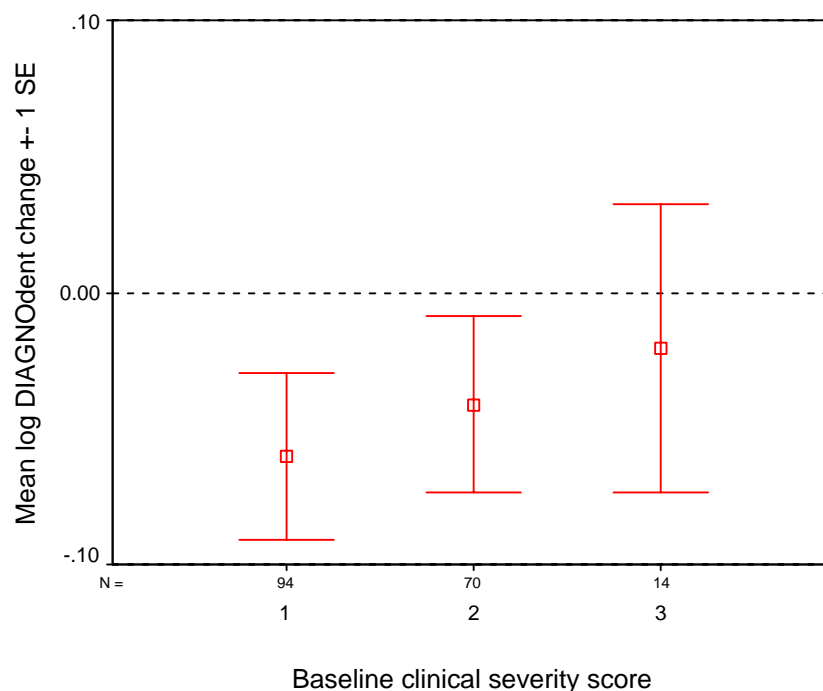


Figure 3: Mean DIAGNOdent readings change categorised by baseline clinical severity scores after 10-second Ozone application time, in-vivo.

DIAGNOdent has many advantages. It is commercially available for the practitioners to use. It is helpful where radiographs are not useful in early occlusal decay or when

patients refuse radiographs. It also gives instant audible feedback to both clinician and patient and involving them in the treatment decision. There are no known risks from use of the DIAGNOdent and it is also easily portable with no need for computer analysis.

Electric caries monitoring

Cariou enamel and dentine are more porous than sound tooth tissue and because they are filled with ion containing saliva fluids, they are less resistant to a small electric current.^{50,51} This was the principle behind the invention of an indirect way to measure the progression and activity of carious lesions, the ECM (Electric Caries Monitor).

Many studies were performed to adapt the principle of the electrical conductance property of human dentition to the dental laboratory and clinical situations. These used many prototypes as well as commercially marketed caries detection machines, which not all were available today (Table 3).

Devices using the electrical conductance property of human dentition	
1	The modified AC Ohmmeter
2	Caries Meter L (G-C International Corp., Leuven, Belgium)
3	Vanguard Electronic Caries Detector (Massachusetts Manufacturing Corp., Cambridge, Mass., USA)
4	ECM I, II, III and IV (LODE Diagnostic, Groningen, The Netherlands)
5	Modified Electrochemical Impedance Spectroscopy (EIS)
6	Electrical Impedance Tomography (EIT)

Table 1: Examples of devices, which used the principle of electrical conductance property of human dentition as an indirect way to measure caries activity.

Various currents, factors that had to be standardised by the operator, calibration procedures, air supplies and validation outcomes were exclusive to each device (Table 2). Thus, no cross comparison of absolute values between studies that used different devices is possible.⁵² Nevertheless, main clinical conclusions could be derived from the clinical studies using these devices.

Factors	Features
Device specifications	
Current used	<ul style="list-style-type: none"> ▪ High or low frequency ▪ Alternate or continuous current ▪ Frequency of alternate current
Electrode	<ul style="list-style-type: none"> ▪ Touching contra-lateral gingival tissue ▪ Touching contra-lateral the cheek ▪ Held by hand
Calibration procedure	<ul style="list-style-type: none"> ▪ In lab using standard resistance units ▪ Internally calibrated
Air flow control	
Air supplies source	<ul style="list-style-type: none"> ▪ 3in1 syringe before the measurement ▪ Connected to the tip and active during measurement
Direction	<ul style="list-style-type: none"> ▪ Operator dependant ▪ Parallel to measuring tip
Air flow meter	<ul style="list-style-type: none"> ▪ Supplied or not ▪ Could be altered or not
Air flow rate	<ul style="list-style-type: none"> ▪ Stable flow or not, throughout the drying period ▪ Amount of flow rate per minute
Air flow time	<ul style="list-style-type: none"> ▪ Time of application was variable
Air operation	<ul style="list-style-type: none"> ▪ Automated or operator dependant
Measurement specifications	
Measurement display	<ul style="list-style-type: none"> ▪ Numbers ▪ Symbols and Colours
Ranges displayed	<ul style="list-style-type: none"> ▪ Small ▪ Large
Type of measurement	<ul style="list-style-type: none"> ▪ Ordinal ▪ Continuous
Units	<ul style="list-style-type: none"> ▪ Ω or none
Measurement procedure	
Number of measurements from each site	<ul style="list-style-type: none"> ▪ One measurement ▪ Multiple and the least single one was chosen ▪ Multiple and the mean was chosen
Protocol for selection of the measuring site	<ul style="list-style-type: none"> ▪ Most severe as detected by vision, ▪ Most severe as detected by other devices, ▪ Most severe as detected by the device
Area of contact between measuring tip and tooth	
Area of contact with the tooth	<ul style="list-style-type: none"> ▪ Tip area only (site-specific) ▪ Area of contact fluid (surface-specific)
Type of conducting fluid.	<ul style="list-style-type: none"> ▪ Saliva of the subject ▪ Various tooth pastes ▪ Saline ▪ NaCl solutions
Area covered by the conducting fluid	<ul style="list-style-type: none"> ▪ A single lesion area ▪ All fissures and pits. ▪ Including cusp tips and marginal ridges
Consistency of conducting fluid	<ul style="list-style-type: none"> ▪ Fluid ▪ Gel
Visualisation of area covered by conducting fluid	<ul style="list-style-type: none"> ▪ Possible by dyed fluid ▪ Not possible (transparent fluid)

Table 2: Various factors, which might affect the validity outcome of the ECM as a diagnostic tool.

As readings varied according to the varied orientation of the dentinal tubules, the modified ohmmeter assumed that the mechanism underlying electric conductance in dentine was related to the transport of ions in the dentinal fluid.⁵³ This principle was used inversely. For a reading taken within a prepared tooth, it was possible to estimate the situation of the pulp horn tips⁵⁴ and calculate the depth of the remaining dentine in crown preparations or in standardised cavities.⁵⁵ The wetting substance used over teeth affected the readings as the higher NaCl concentrations produced lower impedance values.⁵⁶

A clinical cross sectional study used the device to compare caries free premolars in children and adults. Lower impedance values were found in children's teeth compared to adults.^{57,58} Erupting premolars free of soft tissue had electrical resistance values obtained every 3-6 months from the deepest point of the fissure after isolation. Resistance values increased up to 15 months as these premolars matured.⁵⁹ A later study on molars found maturation to be over a period of 36 months.⁶⁰ Using the same device, differences between bovine and the higher resistant human enamel were discovered.⁵⁹

The Caries Meter-L used a colour display in the form of four lights reflecting the status of the tooth; green for no caries, yellow for enamel caries, orange for dentine caries, and red for pulpal involvement.^{61,62} The device was accurate in discovering around 75% of both sound and decayed surfaces in the enamel caries level or around 93 and 63% at the dentine caries level, which were both much better than vision.

The Vanguard electronic caries detector overcame the inconsistency of drying by placing the probe tip centrally and coaxially within a steady stream of air.⁶³ Other than testing cut-off points, the detector was used to predict the need for a sealant or sealant restoration within 18 months after baseline. ECM was a better predictor of caries than visual inspection and Fibre Optic Transillumination.^{64,65} The device was valuable in measuring early lesions which can be monitored longitudinally, thus, it becomes possible to detect the change towards remineralisation, demineralisation or stabilisation.⁶⁶

The ECM by LODE diagnostics took a long path where many versions were tested. At the time of this report, the 4th version is available. Areas on the tooth were possible to be measured using a gel conducting media. This total surface reading was limited by micro-cracks and some anatomical deep fissures besides tooth maturation variations.⁶⁷ Using this technique, an interesting finding was the variation of conductance readings with the season of observation: In the fall, the resistance was lower than in the spring for the same molars studied.⁶⁸

The principle was further extended to measure marginal leakage around fissure sealants in the lab but the clinical situation was still to be considered.⁶⁹ Prediction of caries activity using ECM readings was done. The ECM predicted stability of sound and carious lesions in 75% and 78% of the cases correctly up to 18 months. The remaining percentages were thought to be changed by incidence of new lesions or remineralisation in old ones.⁷⁰

Mineral loss by acids was studied using ECM. The acid etching reduced the resistance readings and brown lesions were more resistant to itching than sound and white-spot decayed samples.⁷¹ Even though it was only tested by the ECM IV LODE tool it can be assumed that stain and brown spot lesions reduce the overall diagnostic performance of ECM in particular for enamel thresholds.⁷² Acid-produced artificial lesions were monitored by the resistance values which inversely related to lesion depth and mineral loss in both enamel and root samples. It was also inversely related to the time of demineralisation, which extended for 4 weeks. It was concluded that the ECM was valuable in monitoring early demineralisations in artificial caries studies.⁷³ Caries removal using Carisolv was as effective in removing carious tissue as conventional drilling as tested by ECM.⁷⁴ Remineralisation using toothpaste was monitored in-vitro.⁷⁵ The mean value of the ECM readings increased as the time of soaking in the toothpaste increased. Enamel samples had a mean change that was larger than the mean change for dentine samples. Further applications were suggested to compare different toothpastes. Validation was recommended for these procedures.

Root caries was tested using the ECM in various ways. The ECM readings were compared to clinical classification criteria for root caries.⁷⁶ Soft dentinal lesion and dark brown lesions had a lower mean integrated value than leathery lesions and light

brown lesions respectively. The ECM gained a good reproducibility by different operators. It correlated negatively with histological lesion depth and positively with remaining thickness of the dentine bridge.⁷⁷ A longitudinal study found earlier that the ECM could detect the deterioration of root lesions in-vivo.⁷⁸ Probing was found to break the superficial layer over root lesions and predisposed to further demineralisation and cavitation. ECM was able to demonstrate this as the mean resistance value for lesions which have been probed and further demineralised was significantly lower.⁷⁹

ECM VI used the vanguard method of drying, as well as a standardised method where the “Standard ECM Scale” procedure was followed. A total drying and measuring time was fixed at 5 seconds and airflow was fixed at 5 L/min. An Integrated Resistance value across the total drying was displayed with an alternating mean resistance value of the last second of drying (the End value). Three to five readings were recommended for each lesion (centre, north, south, east, and west) and the average was calculated to represent the tooth. The tooth was suggested to be re-wetted by saliva, in-vivo, at least 5 seconds between successive readings. The end value is the reading with the maximum number of constant factors mentioned in table 2.

Non-cavitated occlusal carious lesions in 388 teeth from 90 subjects were further examined in one visit following the previous protocol. The effect of 5 seconds re-wetting between the readings was found to be a sufficient wetting agent that was specific for each individual⁴⁷ When half of the lesions in the previous test further received 10-second Ozone treatment, possible immediate changes were tested. No significant ECM change was found immediately after Ozone treatment.⁸⁰

The ECM was found to be a technique sensitive device. As the ECM is a valuable device in monitoring lesions, the repeatability can be improved by observing different factors affecting the resistance readings. It was highly repeatable when excluding readings affected by the technique errors.⁴⁷ These repeatability tests although satisfactory concluded the importance of the training of the investigator as the repeatability might significantly increase by conforming to the following:

- Knowledge of the principle and methodology of ECM application methods and readings analysis.
- Familiarity with the display of different measurements and the relationship of the integrated value to the end value when using the standard scale measurements.
- Understanding of the readings variation from sound to diseased or within the diseased tissue.
- Understanding the effect of the soft tissue or saliva contact to both tooth and the tip apparatus.

Studies to develop and evaluate a new method of spectroscopic Electrical Impedance Tomography (EIT) have been taking place. It aims to reconstructing cross-sectional maps of site-specific electrical impedance spectra (EIS). The tomographic representation will allow diagnostic interpretation of changes in tissue impedance among different locations, instead of being dependent on a single quantitative reading. It would then be used for the detection of small carious lesions.^{81,82}

1.

Figure 4: Diagnosis of occlusal caries using ECM.

Diagnostic system	n	Mean Dz	± SD
Visual inspection	8	0.71	0.39
Fiber-optic transillumination	2	1.08	0.33
Conventional radiography	10	0.89	0.31
Digital radiography	8	0.97	0.27
Xero-radiography	1	0.73	0
Radiovisiography	3	0.91	0.15
Electrical Resistance Measurements	2	1.30	0

Table 3: Mean Dz values measure the accuracy of the methods tested. A higher value means better performance from various diagnostic systems in occlusal caries diagnosis⁸³.

Summary

Many dental practitioners might have a chance to use some of these advanced detection tools. Understanding the following facts would help maximise the benefit gained for the diagnosis of caries:

1. Diagnosis of presence and absence of disease is only a part of the dental caries management process. The responsibility lies on the practitioner to choose which action to follow.
2. Combination of more than one diagnostic tool is strongly recommended for diagnosis process.
3. Each diagnostic tool, conventional or advanced, has some limitations to correctly diagnose lesions at different levels of severity. Optimising the conditions used in the clinical situation would help minimise these limitations.
4. Diagnosis of caries activity proves to be more important than caries severity. Monitoring on the diagnosis and treatment outcomes is indispensable.

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