Changes in Diagnodent Scores in Smooth Surface Enamel Carious Lesions in Primary Teeth: A Longitudinal Clinical Study

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Purpose: To evaluate correlations between Diagnodent laser fluorescence readings and clinical scores for smooth (buccal and lingual) surfaces of primary canines and molars, with particular interest in white spot lesions.

Materials and Methods: A total of 17,088 primary molars and canines in 712 children aged 5 to 7 years residing in the Bayside Health Service District, Queensland, Australia were examined on an annual basis over a 3-year period by one calibrated examiner. Clinical scores and Diagnodent readings were assigned after overlying deposits of plaque had been removed.

Results: Data from a total of 33,029 sites were subjected to frequency analysis using SPSS. Combining buccal and lingual surfaces together, the mean Diagnodent values were: sound (ICDAS 0): 3.3; visible white spot lesion (ICDAS 1+2): 7.7; decay with cavitation into dentine (ICDAS code 5): 37.2; and gross decay with an open cavity (ICDAS code 6): 62.0. Diagnodent scores did not, however, follow Gaussian distributions. White spot lesions showed a significant increase in Diagnodent scores, compared with sound enamel. Longitudinal analyses showed a similar proportion of sites which worsened in both caries score and in Diagnodent score. The same was true for sites which showed improvement over time, indicative of reversal, where Diagnodent scores reduced by 10 or more.

Conclusions: This large-scale clinical study establishes that there is a progression in laser fluorescence scores with increasing severity of smooth surface enamel lesions in primary teeth, from sound smooth surface enamel through white spot lesions and subsequently to cavitation; however, the Diagnodent should not be relied on as the sole means for caries diagnosis because of the possibility of false positive readings if plaque remains on the surface. The joint findings of increased scores with incipient decalcified lesions affecting enamel, and changes in readings aligning with caries reversal or progression lend some support to the clinical use of Diagnodent as an aid in monitoring the progress of early stages of the caries process on smooth surfaces.

Keywords: Diagnodent laser, primary teeth, deciduous enamel, caries diagnosis, ICDAS.

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With emphasis in conservative dentistry focusing in recent years on early lesions, there is now broad recognition that the development of surface cavitation is a late stage in the caries process, and that caries arrest and caries reversal are now more predictable clinical strategies for noncavitated lesions.[1-7] Having said this, the number of pre-cavitation white spot carious lesions typically exceeds the number of clinically detectable cavitated lesions by a considerable margin, and so represent the "tip of the iceberg" in terms of sites with disease present.[1]

Despite wide agreement amongst clinicians on the identification of surface cavitations, the detection of early stages of dental caries (pre-cavitation lesions) has

Table 1 ICDAS categories for smooth surface lesions[10]

Code 0: Sound
Code 1: First visual change in enamel (seen only after prolonged air drying)
Code 2: Distinct visual change in enamel
Code 3: Localized enamel breakdown (without clinical visual signs of dentinal involvement)
Code 4: Underlying dark shadow from dentine
Code 5: Distinct cavity with visible dentine
Code 6: Extensive distinct cavity with visible dentine

A full description of the latest version of ICDAS can be accessed at http://www.dundee.ac.uk/dhsru/news/icdas.htm.

always been problematic. Cariologists internationally now recognize that measures of cavitation which ignore incipient lesions underestimate the true burden of disease. A 2004 review of 29 caries detection criteria systems by Ismail[8] concluded that the majority of the current caries detection systems were ambiguous and did not measure the disease process at its different stages. More recently, several new criteria systems have been proposed and evaluated, both to standardize nomenclature and methodology for clinical trials, and to benefit practitioners in having a more fine-grained approach to assessing early lesions.[9] The "International Caries Detection and Assessment System" (ICDAS) categorizes six stages in the carious process, ranging from the early clinically visible changes in enamel caused by demineralization, through to extensive cavitation (Table 1).[10,11]

Smooth surface lesions on accessible labial, buccal, and lingual tooth surfaces present both an opportunity and a challenge – an opportunity in that they are amenable to subsurface remineralization with fluoride and Recaldent products,[2,3,7,12,13] but a challenge in that monitoring over time is difficult. Probing of smooth surface lesions can damage the surface, while examination of colour changes may be confounded by the uptake of coloured substances within remineralizing tooth structure. Visual examination of lesions is nondestructive, and a number of methods can be used, including fluorescence with visible and ultraviolet wavelengths.

The Diagnodent device exploits the fluorescence properties of bacterial products, in particular protoporphyrin IX, which are found at high levels in cavitated lesions. These are excited by low-power pulsed visible red laser light (655 nm wavelength), and elicit infrared (ie, invisible, 650 to 850 nm wavelength) fluorescence. This photochemical effect occurs regardless of whether the bacteria are in a plaque biofilm, within infected carious dentine, or trapped within subgingival calculus.

There are many studies of Diagnodent technology with conical tips being used on occlusal surfaces to detect fissure lesions, but few studies of its use with broader oval tips on smooth surfaces.[14-17] Most past work has, quite appropriately, focused on permanent molar teeth in adult patients, with much less work on smooth surfaces or on the deciduous (primary) dentition. In south-east Queensland, Australia, the lack of community water fluoridation, together with other factors, has led to dramatically high rates of dental caries in both child and adult populations (fluoridation will be introduced in the coming year). This adverse dental health situation provides an opportunity for a number of focused caries preventive interventions, such as supervised toothbrushing in children in the early years of their schooling.[18,19]

With permanent teeth, several studies have reported that the Diagnodent produces a high diagnostic accuracy for smooth surfaces, with good high inter- and intra-operator agreement.[20-24] Given the dearth of literature regarding the performance of the Diagnodent approach for assessing caries on the smooth surfaces of deciduous teeth, the present study focused on this aspect, aiming to establish the correlations between clinical caries scores on smooth surfaces of primary teeth, and Diagnodent scores.

MATERIALS AND METHODS

Study Population

This study was a component of a larger investigation, an oral health promotion initiative termed "TIPS" (Toothbrushing in Primary Schools).[18] Children in Year 1 schooling (N = 712) from a total of 14 primary schools within the Bayside Health Service District boundaries participated in this research project, after formal ethical clearance had been obtained. The average (median) number of students per school was 59, and ranged from 8 to 110 students. The Bayside Health Service District is situated within the Redlands Shire covering an area of 537 square kilometres, with a mix of urban and semi-rural properties. The district is non-fluoridated, and the reticulated water supply has fluoride levels less than 0.1 parts per million. Children were examined initially for baseline readings, and then again after 12 months and 24 months. At baseline, 63% of the children were 5-year-olds, 37% were 6-year-olds and less than 1% were 7-year-olds.

A single clinician examined each child in the same clinical environment (a purpose-built vehicle with a single chair dental clinic set up for mobile oral health service delivery). Each child was examined in a supine position on a dental chair with the air of an operating light and mouth mirror, and a small ball-ended periodontal probe. Cotton wool rolls and a triplex syringe were used to dry tooth surfaces to enable enamel demineralization to be detected. Caries definitions were kept in close view of the examiner to ensure accurate allocation of irregular measures at each site. Intra-examiner reproducibility prior to baseline examination was tested on a small (N = 25) sample of children of the same age from one school. Weighted kappa coefficients were between 0.85 and 1.00 for agreement at site level measurements. As only one examiner was used, inter-examiner reliability testing was not required. Children with immediate treatment (restorative or otherwise) needs were referred for appropriate dental care. While a significant effort was made to maintain study group participation for the three years, children were lost to follow-up at various stages.

Sample Size

A preliminary statistical power analysis indicated that 1200 sites in the sound and white spot lesion groups would be needed to give sufficient statistical power ($p < 0.05$, Beta = 0.8, threshold = 0.5 %) for fine discrimination at the lower end of Diagnodent scores between sound enamel and white spot lesions. The sample size was increased beyond this to account for drop-out from relocations during the study, taking into account caries rates in the local community and in particular the skewed distribution of caries in this population. In regard to the latter, the large sample size used reflects the need to have sufficient subjects with disease at various stages, recognizing that a large proportion of the study group is potentially disease free.[25] The selection of both canines and molars reflects the known variations in primary tooth caries by tooth type and surface.[26-29] The primary first and second molars are particularly affected by dental caries, compared to the canines and incisors in 6-year-old children.[26-29] As the majority of children in the study were 5 years of age at baseline, deciduous teeth were the most common teeth present at this age. Inclusion of primary canines and second molars was therefore expected to provide a suitable range of sites expected to undergo caries progression or caries arrest/reversal during the period of the investigation.

Clinical Codes

Dental plaque was removed immediately before assessment, and the surfaces dried for 5 s using a triple syringe. The caries score was then assigned. As it was not possible under the conditions of the study to diagnose all possible white spot lesions of enamel, developmental lesions with demineralized enamel affecting the surfaces examined were included in the "white spot" classification, recognizing that even though not caused by caries, some of these can be reversed clinically.[12,13] Thus, lesions with ICDAS codes 1 or 2 were grouped together, as both represented the clinical designation of "white spot" lesions. Where cavitation exposed visible dentine, the carious process had progressed into a stage referred to as "distinct cavitation", which aligns with ICDAS code 5. A cavitation that destroyed at least one half of the buccal or lingual tooth surface was classed as "extensive" (ICDAS code 6).

Diagnodent Assessment

The one clinical examiner and Diagnodent unit (KaVo; Biberach, Germany) were used throughout the study. The Diagnodent unit was calibrated daily using a reference ceramic standard, following the manufacturer's recommendations. The oval recording tips used (tip B)

Table 2 Diagnodent scores for buccal and lingual sites

Code	Subgroup	Number of sites	Mean score
ICDAS 0	All	28,468	3.3
(Sound)	Buccal	13,730	3.3
	Lingual	14,738	3.2
	Canines	15,243	2.4
	Molars	13,225	4.2
ICDAS 2	All	4,286	7.7
(White spot lesion)	Buccal	2,707	6.8
	Lingual	1,579	9.3
	Canines	1,304	5.4
	Molars	2,982	8.7
ICDAS 5	All	178	37.2
(Cavitation involving dentine)	Buccal	97	36.4
	Lingual	81	38.1
	Canines	66	30.9
	Molars	112	40.9
ICDAS 6	All	97	62.0
(Gross cavitation)	Buccal	37	49.4
	Lingual	60	69.7
	Canines	10	48.7
	Molars	87	63.5

The table shows aggregated data for each caries category across 3 years, followed by subgroup data. There was no significant effect of tooth type or tooth surface on Diagnodent scores.

were covered by a cling film sleeve to prevent saliva contamination during use. The sleeve was changed after each patient, in accordance with local infection control requirements.

Readings were recorded for the buccal and lingual surfaces of the deciduous canine and second molar teeth (FDI 55, 53, 63, 65, 73, 75, 83, and 85), moving over the tooth surface in a sweeping action mesiodistally, starting from the cervical area and then moving towards the occlusal table. The maximum reading was noted. The process was repeated and the mean of the two readings used. (Typical variations between these replicate readings were 1 or zero.) Any sites adjacent to buccal restorations (and thus potentially prone to recurrent caries and wall lesions) were excluded from the analysis, since restorations may influence the fluorescence properties of tooth structure. Collection of Diagnodent readings added approximately 5 to 10 minutes to each clinical examination

Relationships between caries scores and Diagnodent data were assessed using SPSS. Data processing was undertaken prior to receipt of the SPSS data file for secondary analysis. De-identified data were double entered by a commercial data entry firm to minimize the potential for typographical errors. Frequency distributions were formally assessed for normality using the Kolmogorov-Smirnov test, and were found to be not normally distributed. Moreover, the presence of a large number of zero values for Diagnodent scores in the "normal" (ICDAS 0) sites meant that log data transformation could not be used prior to analysis. Thus, the nonparametric Mann-Whitney and Kruskal-Wallis tests were used to compare aggregated data for the various caries classifications.

RESULTS

During a total of 2136 appointments, both buccal and lingual surfaces of primary molars and canines were examined, giving some 34,176 sites. Some 1147 sites (3.4% of the total) had to be excluded from the study

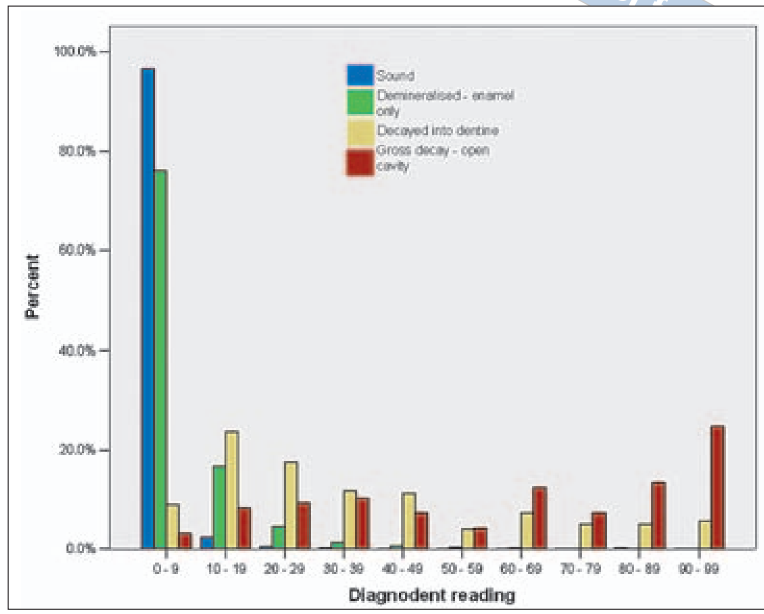

Fig 1 Summary histogram for the four major clinical categories, with Diagnodent scores grouped into bands. Note the different distributions of the scores for sound (blue) and demineralized white spot lesions (green), whereas lesions with small cavitation (light brown) or extensive cavitation (dark brown) have broader and more overlapping distributions. The vertical axis shows the frequency distribution of scores, expressed as a percentage of the total for that lesion type. Detailed information on the calculation method of the scores by the Diagnodent instrument can be found in US patents 6,561,802; 5,897,314; 5,971,755; and 6,135,774.

due to loss or absence of the teeth or due to the fact that the surface was restored or had been covered with a sealant. This left 33,029 sites (aggregated over the 3 years of the study) where valid data could be obtained from visual inspection and Diagnodent.

Aggregated Data

Overall, 13.0% of the sites examined were affected by incipient enamel caries, but only 0.5% had caries involving dentine, and 0.3% had gross caries with large open cavitations.

The variations within the aggregated data sets due to site location (buccal or lingual) or tooth type (canine or molar) are shown in Table 2, but these were not statistically significant. These data have been shown as means to allow comparison to other studies in the literature (albeit with smaller sample sizes). However, as already stated and as seen in the histogram presentatations of frequency distributions (Figs 1 and 2), Diagnodent readings did not follow a Gaussian (normal) distribution.

Looking more closely at the data for "sound" and "demineralized" surfaces (white spot lesions), the modes for these two distributions are 2 and 3, respectively, but the distributions are significantly different with a much larger "tail" in the white spot lesion data (Fig 2). The mode (most frequent value) for sound sites (with a frequency of 38.5%) was a score of 2, while for white spot lesions the mode was 3 (with a frequency of 16.8%). For both classes of cavitated lesions, scores were distributed from a low of 9 up to the maximum value of 99.

Longitudinal Data

Sequential data from a total of 467 children over the 3-year period were available. While some teeth had been lost during the period of the study due to exfoliation, restoration or extraction, there were still 7050 matched surfaces from each year which could be included in the longitudinal analysis. Over the 3-year period, there were relatively few changes in surface conditions or in Diagnodent scores, with nearly 90% of sites showing no change in either (Table 3). Of interest however, a similar proportion of sites which worsened showed an increase in both caries score and in Diagnodent score. The same was true for sites which showed improvement (ie, a lower caries score, indicative of reversal); a reduction in Diagnodent score of 10 or more was also observed.

DISCUSSION

This large-scale clinical study provides both cross-sectional and longitudinal data on the relationship between clinical caries assessment on smooth surfaces of pri-

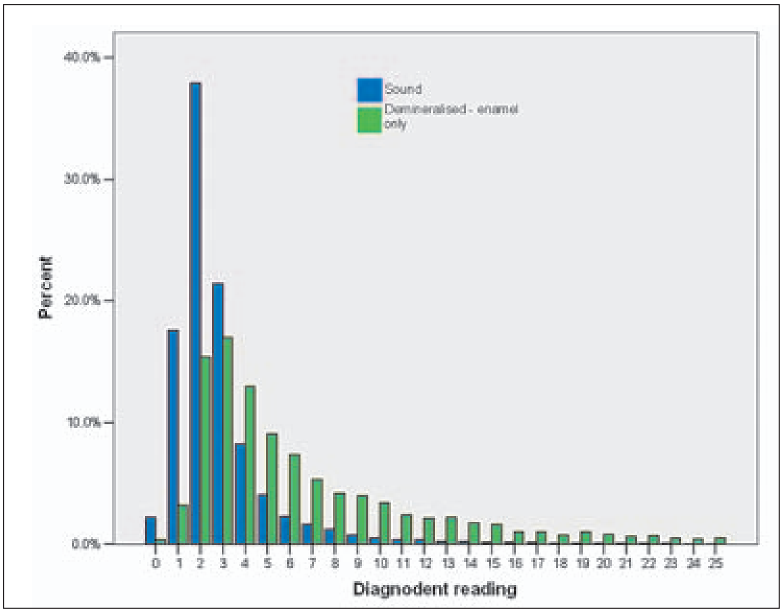

Fig 2 Detailed histogram of frequency distributions for sound smooth surfaces (blue bars) (N = 28,468 sites) and demineralized white spot lesions (green bars) (N = 4,286 sites), showing the “tails” of each. As with Fig 1, the vertical axis shows the frequency distribution of scores, expressed as a percentage of the total for that lesion type.

Table 3 Transitions over the study period

Change in caries score	Percent sites	Change in Diagnodent score	Percent sites
Change – 2 (improvement)	0.1%	Change – 20 (improvement)	1.2%
Change – 1 (improvement)	3.9%	Change – 10 (improvement)	6.3%
Zero change	88.8%	No change	88.7%
Change + 1 (worsening)	5.5%	Change + 10 (worsening)	3.5%
Change + 2	0.4%	Change + 20	0.3%
Change + 3	0.4%	Change + 30	0

In the caries score, a change of 1 indicates a movement between the values of sound (0), white spot (1), cavitation involving dentine (2), and extensive cavitation (3), between the year 3 score and the baseline score. For Diagnodent scores, the data show the final score minus the baseline score, aggregated into bands of 10.

mary teeth and Diagnodent scores. The results add to existing knowledge regarding the use of the Diagnodent in two significant ways.

First, the present study shows that there is an increase in Diagnodent scores in white spot lesions compared with sound enamel, as evidenced in both aggregated and longitudinal analyses. This phenomenon has not been characterized previously. The long “tail” in the distribution of Diagnodent scores in white spot lesions is in agreement with the well-established nature of the active white spot lesion, where the surface is porous because of the ongoing action of bacterial acids, allowing, at least at the microscopic level, bacterial products such as protoporphyrins as well as organic acids to enter the surface of the enamel. The most porous lesions would be expected to demonstrate higher scores, as bacterial products penetrate in greater amounts. Whether this effect is identical in permanent teeth or is more noticeable in primary teeth (which contain more water and less mineral in their enamel than permanent teeth) remains to be explored.

The second aspect of this study which is of importance is the parallel between changes over time in clinical caries scores and in Diagnodent scores. An increase in Diagnodent scores would be expected with increasing severity of enamel lesions in primary teeth, from sound smooth surface enamel through to white spot lesions and subsequently to cavitation. A small percentage of lesions regressed over the period of this study, and there was an accompanying reduction in their Diagnodent scores, in terms of aggregated data. Tracking of individual sites[24] may therefore provide evidence to support caries arrest, as demonstrated in a recent clinical study of individual cervical surfaces.[30] Provided that plaque is removed (to prevent false positive scores) and surface stains do not impair the eliciting or emitted light, clinical use of Diagnodent as an aid in monitoring the progress of early stages of the caries process on smooth surfaces could be viable.

Aligned with this approach would be clinical strategies for managing incipient caries. Following a minimum-intervention approach, patients with re-cavitation lesions should undergo a structured caries risk assessment, for example, using saliva and plaque tests to design an appropriate home care plan, and so that advice to the patient can be personalized in terms of diet, lifestyle factors, and oral hygiene.[7,31,32] White spot various lesions can be treated with topical Recaldent or Recaldent-fluoride combination products (GC Tooth Mousse and Tooth Mousse Plus, respectively; GC; Tokyo, Japan) to reverse the subsurface mineral loss, and achieve a normal enamel translucency.[2,12,13] Preventive care of this type is indicated for all noncavitated enamel lesions on smooth surfaces – including proximal surfaces. A recent large-scale clinical trial conducted in Melbourne has demonstrated the value of Recaldent for lesion arrest and reversal, even in patients who live in fluoridated areas and who are using traditional preventive approaches, including a fluoride dentifrice, and access to professional dental care.[33] Combining the effective monitoring of white spot lesions and the use of remineralizing products offers a way forward for maximum interception of white spot carious lesions.[34,35] Since this study was concluded, enhancement of Diagnodent performance for assessing smooth surface lesions has occurred with new designs of the device,[36-38] and various water soluble cationic porphyrin dyes, such as tetrakis-(N-methylpyridyl)-porphyrin,[39] have been used to treat the tooth surface prior to recording, to gain greater information on surface porosity. These advances may increase the sensitivity and specificity of Diagnodent readings for white spot lesions.

CONCLUSIONS

This clinical study suggests that changes in Diagnodent laser fluorescence scores with time may assist with maximum interception strategies directed at white spot lesions. In so doing, it extends the results of laboratory studies of smooth surface caries-like lesions created by pH cycling rather than by cariogenic biofilms.[40] In the clinical situation, the presence of bacterial products may explain the improved performance of the system. This study also goes some way to addressing aspects of Diagnodent use in vivo which have yet to be fully explored.[41]

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