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A follow-up study of the use of DIAGNOdent for monitoring fissure caries in children

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Abstract – *Objectives:* The aim of this study was to evaluate the utility of the laser fluorescence device DIAGNOdent for monitoring occlusal caries longitudinally as part of a routine dental check-up in a public dental clinic. *Methods:* Children aged 7–8 and 13–14 years at baseline participated in the study. As part of two consecutive dental check-ups with a mean interval of 1,19, years, 423 permanent molars and 315 primary molars in 81 children were examined visually and using DIAGNOdent by one dentist. In teeth where, as judged by visual examination, caries had emerged or progressed during the follow-up, the DIAGNOdent values had increased significantly from the baseline. *Results:* In permanent teeth with a change in visual score from sound to enamel or dentin caries, the mean DIAGNOdent value increased from 24 to 37 and in primary teeth from 8 to 40. The increase in DIANGOdent values correlated positively with the increase in visual score. The mean DIAGNOdent value at baseline was significantly higher in teeth that became carious than in those that remained sound during the follow-up. For permanent teeth with a visual reversal from inactive or acitve enamel caries to a sound surface, the mean DIAGNOdent value decreased from 36 to 24. *Conclusions:* These results suggest that DIAGNOdent is useful in monitoring occlusal caries in both permanent and primary molars.

Key words: DIAGNOdent; fissure caries; laser fluorescence; monitoring

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The laser fluorescence device DIAGNOdent is increasingly used as an adjunct to visual examination for detecting occlusal caries. DIAGNOdent has been found to be reasonably accurate, and the reproducibility of measurements has been high both *in vitro* and in clinical studies (1–9). In our recent study, we evaluated the utility of DIAGNOdent for diagnosing occlusal caries as part of routine dental check-ups for a convenience sample of 109 children aged 7–8 and 13–14 years (10). The results of visual and radiographic examinations and DIAGNOdent measurements were compared. To provide a gold standard for carious teeth, the depth of the caries lesion was determined in those lesions that were judged visually to need opening by drilling. At a cut-off value of >30 for operative intervention, the sensitivity of DIAGNOdent was 92% and the specificity 82% when validation was based on observation of fissures opened with a drill. The accuracy of DIAGNOdent has been of the same order of magnitude in other studies, although in general, the cut-off values used for dentine caries have been lower. The results of DIAGNOdent measurements and visual examination by an experienced dentist agreed fairly well, which is in concordance with clinical results of Alwas-Danowska et al. (7). Radiographic examination was least accurate. We found a distinct difference in the mean DIAGNOdent values for enamel lesions, which were judged visually as active or inactive.

It has been suggested that DIAGNOdent could be used for monitoring caries lesions. So far, however, no longitudinal studies of DIAGNOdent have been published. The aim of this study was to monitor progression and arrest of caries in occlusal fissures using visual inspection and DIAGNOdent at routine

follow-up examinations of the same children whose baseline recordings had been performed in the context of the above-mentioned study (10).

Material and methods

Subjects

The baseline study sample consisted of 109 voluntary children in the first (7- to 8-year olds) and seventh grades (13- to 14-year olds) at two schools in Oulu, Finland. The children who volunteered for the study attended routine dental check-ups at a public dental clinic in 2001. Informed consent had been obtained from the parents of those for whom radiographs were to be taken for the purpose of the baseline study. Details of the sampling procedure have been presented in the paper of Anttonen et al. (10). All children who attended the baseline examination were invited for a second check-up in 2002. Twenty-eight children were lost to follow-up. They had either moved, or did not arrive for the examination, or arrived for the examination so late that the interval between the two check-ups would have been too long. The drop-outs were excluded from the study. The final study group consisted of 81 children of whom 42 were 8- to 9-year olds and 39 14- to 15-year olds in the end of the follow-up. The mean interval between the two check-ups was 1.19 years (SD 0.18).

Visual examination

A public health dentist (V.A.), who is experienced in diagnosing occlusal caries and familiar with the use of the DIAGNOdent device, carried out all clinical procedures in both examinations. The teeth were not cleaned professionally before inspection. First, all molars were dried lightly with an air syringe and the occlusal surfaces were examined visually. The light of the unit was used without any magnification device. The probe was used to feel the texture and the roughness of the occlusal surface. In sealed teeth, mainly visual examination was used. Clinical status was recorded as shown in Table 1.

DIAGNOdent measurements

Measurements with the DIAGNOdent device (KaVo, Biberach, Germany) were made after calibration of the device with a ceramic standard for each patient in the similar manner as in the baseline examination (10). The occlusal surface of the tooth was briefly air-dried and the tip of the device was placed on the tooth surface to be measured. Measurements were performed moving and tilting the conical tip A on the occlusal surface. The whole occlusal surface was scanned. The acoustic signal was on and helped to find the site with the most severe demineralization. A dental assistant called out the readings while the dentist made the measurements. The maximum reading for each surface was recorded. The same tip A was used both initially and in the follow-up examination. In the teeth with a fissure sealant, the measurements were made through it. All sealants were of clear type.

As in the case of the baseline study (10), no differences in the distribution of DIAGNOdent values were found between the two age groups or between the first and second molars. Therefore, the data of all permanent molars for both age groups were pooled.

Reproducibility

The reproducibility of the visual caries scores and the DIAGNOdent measurements was determined only at baseline. For this purpose, the occlusal surfaces of 102 teeth in 11 children were re-examined on a different occasion, the time between the two examinations being about 4 weeks. The kappa value for visual examination was 0.85 (scores 0, 1, and 2 versus 3). The mean DIAGNOdent values of the consecutive measurements were 33.3 and 31.3, respectively, implying negligible systematic error.

Table 1. Criteria for visual examination

Score	Category	Criteria
0	Sound	Normal enamel texture
1	Inactive enamel caries	The fissure enamel is brownish or black. The surface feels hard and smooth. No loss of substance
2	Active enamel caries	The fissure enamel is opaque with loss of luster. The surface feels rough. No loss of substance
3	Dentinal caries	The fissure enamel is opaque and feels soft. The subsurface dentine around the fissure appears dark. Often loss of substance, but not necessarily

Pearson correlation coefficient and intraclass correlation coefficient were used to assess the extent of random error. The values for these coefficients were 0.74 and 0.78, respectively (10).

Statistical analyses

To illustrate the surface-specific differences between the visual examination score at baseline and that at follow-up, a change parameter (the value at follow-up minus the value at baseline) was calculated. A corresponding change parameter was used to describe the direction and extent of the surface-specific differences in DIAGNOdent values between the two examinations. In the graphs illustrating the percentage distribution of tooth surfaces according to the value of the change parameter, the values were grouped into 10-unit categories. Box plots were used to illustrate the distribution of DIAGNOdent values in different categories of the visual examination score. The statistical significance of the differences in the mean DIAGNOdent values among different groups of teeth was assessed using a two-level hierarchical ANOVA model that was fitted to the data using SAS PROC MIXED as suggested by Singer (11). The model has two error terms, one measuring the variation between different children and the second representing variation within the same child.

Ethical approval

The ethics committee of the city of Oulu gave its approval for this study.

Results

A total of 423 permanent molars and 315 primary molars in 81 children were examined at both check-ups using visual inspection and DIAGNOdent.

Of all the permanent molars examined, 110 had a clear sealant in both check-ups and 204 in the latter check-up. The mean DIAGNOdent values for sealed and unsealed teeth in the latter check-up are shown in Table 2. The mean values between sealed and unsealed teeth were not significantly different in teeth with a visual score 0–2. As a result of the small number of cases with score 3, statistical testing was not possible in this category. The percentage distribution of teeth according to the difference in visual score registered at the two check-ups is shown in Fig. 1. The respective distributions of teeth according to differences in the two consecutive DIAGNOdent values are shown in Figs 2 and 3.

Figure 4 shows the distribution of DIAGNOdent values among permanent and primary molars that were visually sound at the first check-up but had scores of 1, 2 or 3 at the second check-up. For both primary and permanent teeth, the DIAGNOdent values were significantly higher at the follow-up than at baseline (permanent teeth: $P < 0.0001$, primary teeth: $P = 0.026$).

To study whether DIAGNOdent values changed when data from visual examination showed progression of lesion, the mean DIAGNOdent values were calculated separately for permanent molars with changes $0 \rightarrow 1, 0 \rightarrow 2, 0 \rightarrow 3, 1 \rightarrow 2$ and $2 \rightarrow 3$ in visual score (Fig. 5). There was a distinct increase in the mean DIAGNOdent value for all these teeth; but because of the small number of cases, the differences between the baseline and follow-up values were statistically significant only for teeth with a change $0 \rightarrow 1$ and $0 \rightarrow 2$ ($P = 0.017$ and 0.0004, respectively). Among primary molars with a change $0 \rightarrow 1$ or $0 \rightarrow 2$, the mean DIAGNOdent value increased from 11 to 26 ($n = 15$, $P = 0.208$) and for those with a change $0 \rightarrow 3$ the value increased from 3 to 74 ($n = 6$, $P = 0.028$).

To study whether visual examination showed progression of lesion when DIAGNOdent values changed, the teeth were cross-classified according to changes in DIAGNOdent values and visual score (Table 3). A difference of ≥20 units in DIAGNOdent values between baseline and follow-up was considered a change. In teeth where DIAGNOdent value increased, visual score increased in 56% of cases and in 40% no change was found. In 81% of teeth where DIAGNOdent value decreased, visual value decreased or remained the same. In 80% of cases where the change in DIAGNOdent value was <20, visual score remained unchanged. Overall, in 74% of teeth, the results of the two measurements were concordant.

Table 2. Mean DIAGNOdent values (SD) for sealed and unsealed teeth in different categories of visual score

	Visual score							
	0		1		2		3	
	Mean (SD)	*n*	Mean (SD)	*n*	Mean (SD)	*n*	Mean (SD)	*n*
Sealed	22 (22)	122	34 (25)	56	47 (21)	23	76 (23)	3
Unsealed	16 (14)	179	32 (22)	79	44 (27)	25	60 (21)	16

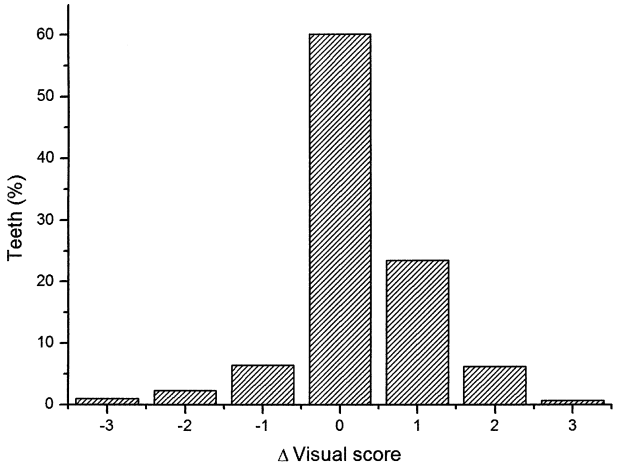

Fig. 1. Percentage distribution of permanent molars according to the difference in visual score (Table 1) determined at baseline and at follow-up (follow-up minus baseline).

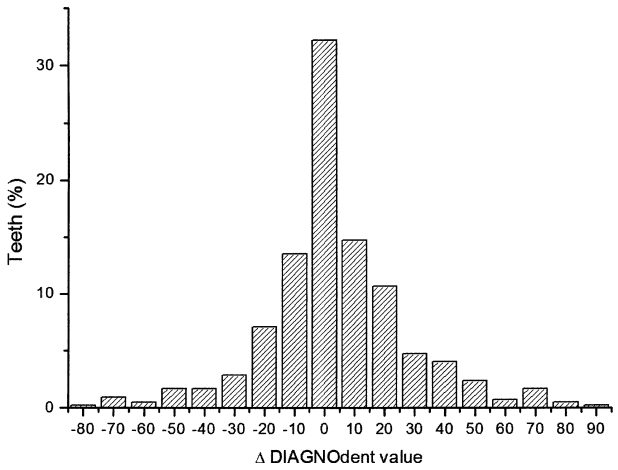

Fig. 2. Percentage distribution of permanent molars according to the difference in DIAGNOdent value measured at baseline and at follow-up.

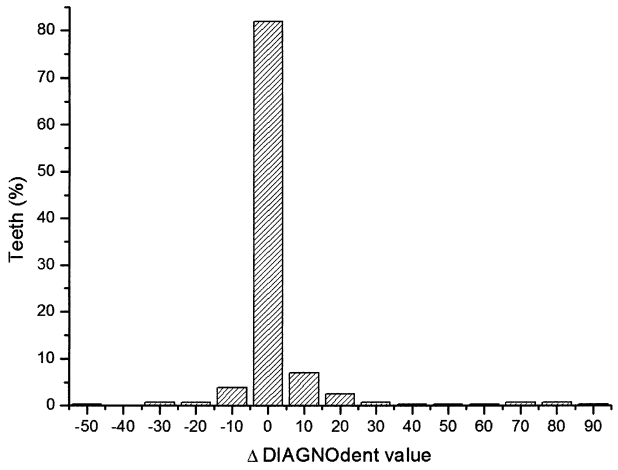

Fig. 3. Percentage distribution of primary molars according to the difference in DIAGNOdent value measured at baseline and at follow-up.

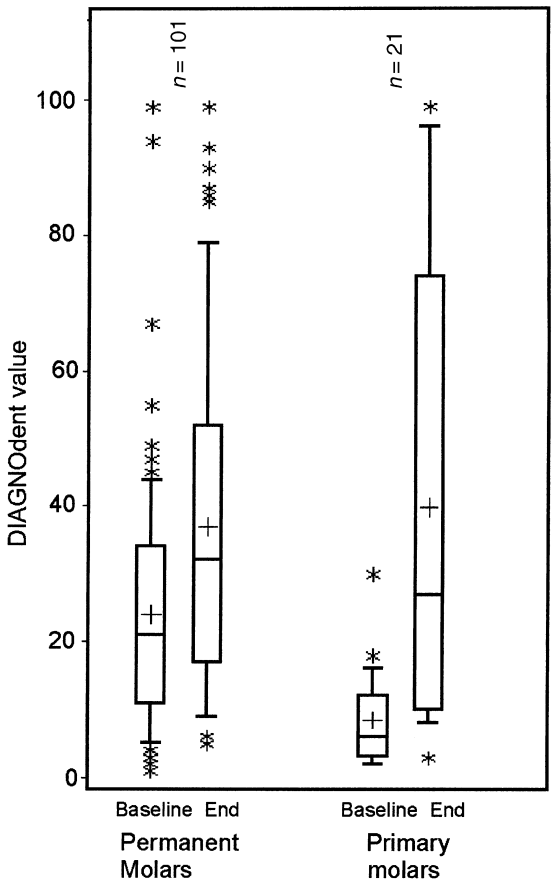

Fig. 4. Box plots describing the distribution of DIAGNOdent values for teeth which had a visual score of 0 at baseline and a score of 1, 2 or 3 at follow-up. Data for first and second molars and for younger and older children were pooled. Interpretation of a box plot: + = mean, − = median. The box extends from the lower to the upper quartile, and the whiskers extend from the 10th to the 90th percentile. More extreme values have been plotted by *.

There were 254 teeth where visual score had remained unchanged during the follow-up. For those having visual score 0, 1 or 2 at both occasions, the mean change DIAGNOdent values were 3 (SD 18), −5 (SD 22) and 3 (SD 30), respectively. All teeth with visual score 3 at baseline had been filled.

For permanent molars having a visual score of 0 at both the first and second check up, the mean baseline DIAGNOdent value was 16 ($n = 198$) and for those with a visual score of 0 at baseline and a follow-up score of 1, 2 or 3, the mean DIAGNOdent value at baseline was 24 ($n = 101$). For primary molars, the respective mean values were 4 ($n = 281$) and 8 ($n = 21$). The difference in the baseline values between teeth that remained sound and those that developed caries was statistically significant for both permanent and primary molars ($P = 0.001$ and $P < 0.0001$, respectively).

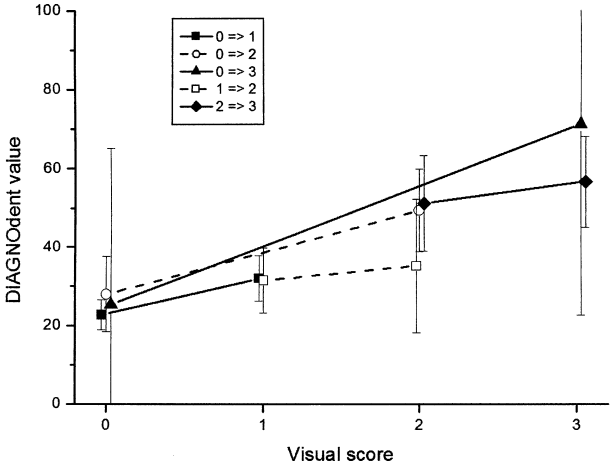

Fig. 5. The mean baseline and follow-up DIAGNOdent values (with 95% confidence intervals) for permanent teeth in which the visual score increased during the follow-up. Numbers of cases: $0 \rightarrow 1, n = 75; 0 \rightarrow 2, n = 23; 0 \rightarrow 3, n = 3; 1 \rightarrow 2, n = 11; 2 \rightarrow 3, n = 13$.

In 19 permanent molars, the visual score had reversed from 1 or 2 to 0. For these teeth, the mean baseline DIAGNOdent value was 36 and the follow-up value 24 ($P = 0.086$). All teeth with a visual score of 3 at the first appointment had been filled. Only four primary molars with a visual reversal were found. For these teeth, the mean baseline DIAGNOdent value was 28 and the follow-up value was 22 ($P = 0.716$).

There were 53 permanent molars that at baseline had a visual score of 0 but a high DIAGNOdent score (>30, mean = 46). At follow-up, the mean DIAGNOdent score for these teeth was 41. Of the teeth, 47 had a visual score of 0 or 1, six had a score of 2 and one had a score of 3 at follow-up.

Discussion

At the follow-up examination, no validation was performed, as both visual examination and DIAGNOdent measurements had been validated at baseline examination using fissure opening for those teeth where caries had apparently extended to dentine. In a clinical study, fissure opening is not ethically acceptable for less extended lesions. However, even for initial caries, the results of visual and DIAGNOdent measurements seemed to agree fairly well at baseline study.

For teeth in which, according to visual examination, caries had developed or progressed during the follow-up, the mean DIAGNOdent values were clearly higher at the follow-up examination than at baseline. This was true for both permanent and primary teeth. The increase in values correlated positively with the change in the visual examination score, i.e. the change in the activity and depth of the lesion according to the visual examination. In primary molars, the increase was especially pronounced because of the low values for sound teeth. In six primary molars, which according to visual examination were sound at baseline and had dentine caries at follow-up, the mean DIAGNOdent value had increased from 3 to 74 and in all these teeth the follow-up value was >35. The low baseline value for sound primary teeth is in accordance with the results of Lussi and Francescut (3). The values for enamel and dentine caries were of the same order of magnitude as those in permanent teeth, as was already found in our previous study (10) and in the study by Lussi and Francescut (3).

An important finding was that in permanent teeth that were visually sound at baseline but had enamel or dentine caries at follow-up, the mean initial DIAGNOdent value was significantly higher than in those that were visually sound both at baseline and at follow-up (24 versus 16, $P = 0.001$). These results suggest that, regardless of the visual appearance, teeth with a baseline value of >20 are more likely to become carious than those with a lower value. Many of these teeth probably had invisible initial enamel caries already at baseline, which might have been discovered if professional cleaning and thorough air-drying had been done. Based on this result, intensified self-care,

Table 3. Cross-tabulation of the teeth (numbers and percentages) according to changes in DIAGNOdent value and visual score

	≥1 step decrease in visual score	No change	≥1 step increase in visual score	Total
≥20 unit decrease in DIAGNOdent	17 (30)	29 (51)	11 (19)	57 (100)
<20 unit change in DIAGNOdent	27 (6)	478 (80)	89 (15)	594 (100)
≥20 unit increase in DIAGNOdent	3 (3)	35 (40)	49 (56)	87 (100)
Total	47 (6)	542 (73)	149 (20)	738 (100)

prevention and follow-up are indicated for children that have visually sound teeth but elevated DIAGNOdent values.

In permanent molars with a reversal from inactive or active enamel caries to a sound surface as determined by visual examination, the mean DIAGNOdent values had decreased considerably although, because of the small number of reversals, the difference was not quite statistically significant. This suggests that DIAGNOdent may also be helpful for diagnosing reversals in permanent teeth and be a sign of the success of prevention or improvement the self-care. In the four primary molars with a visual reversal, the follow-up DIAGNOdent value was only slightly smaller than the baseline value.

At baseline, the sensitivity of DIAGNOdent with validation by fissure opening was 92% and the specificity was 82%, and with visual examination for validation the respective values were 92% and 69% (10). The accuracy of DIAGNOdent is thus far from 100%, as was also found in other studies (1–3, 5, 7, 9). At baseline, there were 53 permanent molars, which with visual examination were sound but had a high DIAGNOdent value of >30 (mean = 46). Radiographic examination of these teeth at baseline did not reveal dentinal caries (10). At the follow-up, the mean DIAGNOdent value had somewhat decreased but was still 41. However, when judged visually, only seven of the teeth had developed active enamel caries or dentinal caries. All 53 teeth should be monitored further, but so far the results suggest that a high DIAGNOdent value does not necessarily imply that a tooth has progressing dentine caries.

When the data were turned the other way round, i.e. clear changes versus little or no changes in DIAGNOdent measurements were cross-classified with corresponding categories of visual score, the recordings were concordant in 74% of cases. This suggests that even a relatively large change in DIAGNOdent value is not necessarily reflected as a change in visual examination score. However, in only 2% of the cases the recordings were quite opposite to each other so that the value of one had increased and that of the other had decreased.

About half of the permanent molars had a clear sealant, through which the measurements were made. At baseline, the mean DIAGNOdent values were similar for sealed and unsealed teeth (10) and therefore teeth with a sealant were also included in the follow-up. According to the results, the mean values for sealed and unsealed teeth did not differ in any category of visual score at the follow-up, either. It may sound strange that not all sealed teeth have a low DIAGNOdent value. The reason for this is that, because of the known difficulty of detecting occlusal caries, sealed teeth may have had enamel and even dentine caries that has remained undetected when the sealant has been placed. Caries may also develop under a faulty sealant. It can be diagnosed visually through a clear sealant and scored the same way as caries in an unsealed tooth. Our results both at baseline and at follow-up suggest that DIAGNOdent values are not significantly affected by clear sealants, either. This agrees with the *in vitro* results of Takamori et al. (12).

It is currently recommended that the DIAGNOdent device should be zeroed on a sound tooth surface before the measurements are made. In the instructions provided for the device in 1998 this was not mentioned; and when the study was started, we were not aware of the latest recommendations. Therefore we did not zero the device on a sound surface at the first examination and intentionally refrained from zeroing even at the second one. According to our later experience, zeroing has in general a very small effect on the readings (1–2 units). In the present setting, its omission did not affect comparison of the values, as the calibration was accomplished in a similar way in both studies.

In this study, teeth were not cleaned professionally at baseline or at follow-up, as the original aim was to study the use of DIAGNOdent as part of a routine check-up. Professional cleaning is time consuming. In Finland, it is not included in routine check-ups, because among Finnish children bad oral hygiene seldom prevents proper visual inspection. In the instructions of DIAGNOdent it is advised that the teeth be cleaned professionally, although to our knowledge the effect of cleaning on DIAGNOdent values has not been studied clinically. Further studies are needed to ascertain whether cleaning is necessary for persons with good oral hygiene. However, as cleaning was omitted at both check-ups in our study, the differences between the DIAGNOdent values of the two check-ups were not affected.

These results suggest that DIAGNOdent is useful for monitoring progression and arrest of occlusal caries in both primary and permanent molars. An experienced clinician does not necessarily need any

device. However, DIAGNOdent may act as an alarm in borderline cases. For less experienced dentists and dental auxiliary staff, DIAGNOdent may be useful as an adjunct to visual examination in routine use.

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