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ORIGINAL ARTICLE

Accuracy of tactile assessment in order to detect proximal cavitation of caries lesions in vitro

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Abstract

Objectives Discriminating non-cavitated from cavitated proximal lesions without tooth separation is only limitedly possible using visual-radiographic assessment alone. We evaluated how additional tactile assessment might increase the accuracy of this discrimination in vitro.

Methods Surface integrity of 46 primary molars with proximal lesions extending radiographically into outer third of dentin (ICDAS-codes: 2 $n = 34$, 3 $n = 8$ and 5 $n = 4$) were mounted in groups of two in manikin heads and independently assessed by three examiners using visual-radiographic and additional tactile assessment using a cow-horn-ended explorer with or without gingival displacement. After examination, lesion surfaces were evaluated for possible damage using scanning-electronic microscopy. Analysis of variance (ANOVA) was performed for evaluating if tactile assessment and gingival displacement significantly affected accuracy.

Results Tactile assessment significantly increased sensitivity of detecting cavities ($p < 0.001$, ANOVA), but decreased specificity ($p < 0.05$). Sensitivities/specificities varied between 33 (8)%/96 (1)% and 86 (6)%/84 (5)%. Gingival displacement had no significant impact on accuracy ($p > 0.05$). Scanning-electron microscopy revealed no cavitation.

Conclusions In vitro, tactile assessment of proximal surfaces was useful and safe.

Clinical relevance Analysis of the cavitation level by using a cow-horn-ended probe might be leading to useful information in addition to bitewing assessment under clinical circumstances.

Keywords Caries · Detection · Diagnosis · Proximal lesion · Explorer · Probing

Introduction

The detection of posterior proximal lesions is usually based on a screening process using visual and radiographic measures [1] followed by a more detailed assessment of detected lesions regarding their extension and activity. For such proximal lesions, the assessment of the surface integrity is widely seen as most important, since non-cavitated lesions are supposed to be remineralizable, whilst most cavitated lesions require restorative interventions [2, 3].

To detect surface cavitation of medium-sized proximal lesions, the described combination of visual and radiographic means was shown to be not sufficiently reliable [4–7], but no validation study of this procedure has been published to our knowledge so far. Even though assessing such lesions with a blunt probe, as recommended for smooth-surface lesions, is theoretically possible, such blunt and often ball-ended probes may be unsuitable for interdental probing due space restriction and only used after tooth separation. The use of a so-called sharp dental explorer, however, is feared to possibly damage formerly intact lesion surfaces mainly occlusally [8–10], but also on smooth surfaces [10].

We hypothesised that gentle proximal probing using a fine bended 'cow-horn' explorer may be helpful and safe to assess

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surface integrity of proximal lesions. Additionally, before treating such lesions either micro- or minimally invasive, rubber dam application and interdental separation using wedges may be useful to confirm the initial diagnosis. We hypothesised that, at this stage, careful probing may allow improved assessment of surface integrity of identified lesions, with gingival displacement by rubber dam and wedge possibly improving validity and reliability of the assessment.

Thus, the present study investigated sensitivity, specificity and reliability of detecting cavitated proximal lesions in primary molars by visual-radiographic means and additional proximal probing in vitro.

Materials and methods

One-hundred and three extracted or exfoliated primary molars with at least one proximal lesion were used. The study protocol conformed to the principles outlined in the German Ethics Committee's statement for the use of human body material in medical research [11]. After careful cleaning, teeth were independently assessed by two experienced calibrated examiners (HML; SP), and proximal lesions were coded according to the International Caries Detection and Assessment System [ICDAS] [12]. Eighty-seven teeth with ICDAS scores 2, 3 and 5 were selected and fixed with their root remnants in acrylic resin (Technovit 4071, Heraeus Kulzer, Wehrheim, Germany) adjacent to a sound primary molar, with the carious and sound proximal surfaces being in a natural-like contact position; i.e. the lesion was between 1 and 3 mm below the proximal contact point in the middle of the 'buccal-oral' orientation. Subsequently, the resin base was sectioned, remounted and fixed (Lego, Grasbrunn, Germany), simulating healthy periodontal mobility of teeth during separation. Gingiva was simulated using polyvinyl-siloxane (Honigum, DMG, Hamburg, Germany) covering cervical and proximal surfaces 1 mm above the enamel-cementum junction and up to the contact point, respectively (Fig. 1). Bitewing radiographs of mounted teeth were then obtained (Gendex, Kavo, Biberach, Germany) and classified by one trained examiner (HML) as radio-translucencies reaching into the inner half of enamel (E2), outer third (D1) or middle third of dentin (D2) [13]. Based on ICDAS-classification and radiographic scores (only extending into outer third of dentin), 46 teeth with rather clear clinical signs were selected (HML) for the main experiment. These represented proportions of ICDAS and in consequence cavitation status reported in a previous clinical study for lesions extending radiographically into outer third of dentin [14] (ICDAS-codes: 2 $n = 34$, 3 $n = 8$ and 5 $n = 4$) representing the gold standard for the study.

Fig. 1 Mounted primary teeth with simulated gingiva

For the main experiment, each tooth pair was independently examined by the three dentists; two experienced clinicians (VS, SP) and one trained postgraduate student (JL). Teeth were mounted in the third quadrant of manikin heads (EWL G40, Kavo). The carious proximal site to be evaluated was randomly placed facing either mesial or distal. The three examiners were first calibrated for clinical and radiographic caries assessment on all 87 primary molars following the same diagnostic procedures step-by-step as done in the main experiment with $n = 46$ performed 2 weeks later. The examiners were not aware of the frequency and distribution of various ICDAS scores. For each proximal surface to be evaluated, the examiners first read the respective radiograph and then visually examined the carious tooth site using a plane dental mirror (MIR4, Hu-Friedy, Tutlingen, Germany) without magnification aids. Examiners recorded the surfaces as non-cavitated (ICDAS 2), cavitated into enamel (ICDAS 3) or cavitated into dentin (ICDAS 5). Immediately after, they again examined the teeth, this time using a fine cow-horn ended explorer (EXD 3 CH, Hu-Friedy) for very gentle (less than 100 g force) proximal probing, followed again by a decision regarding surface status of lesions. One week later, the same assessment was performed in all 46 teeth to evaluate intra-observer reliability. Again, 1 week later, rubber dam (Pluradent, Offenbach, Germany) was applied, and examiners evaluated the surface status first with the cow-ended probe only as described above. Second, examiners were allowed to displace the interdental mock gingiva with a flattened plastic wedge (Icon, DMG, Hamburg). This experiment was also repeated after 1 week for reliability assessment.

Replica of evaluated proximal surfaces were manufactured using polyvinyl-siloxane (Honigum) and epoxy resin (Stycast 1266, Emerson Cuming, Canton, USA). Surfaces were inspected by an independent examiner (FS) using a scanning-electron-microscope (Phillips XL 30CP) at × 50 magnification to assess possible scratches or cavitations on proximal surfaces only after the experiment.

Statistical analysis was performed with SPSS 20 (IBM, Armonk, USA). Sensitivity and specificity of detecting cavitated lesions were analysed separately for lesions with ICDAS code 3 and 5, respectively, as well as pooled for all lesions using contingency tables. Additionally, overall accuracy was

calculated (sensitivity + specificity − 1, range 0 to 1). Influence of factors (assessment method, ICDAS code, experience of examiner, use of rubber dam and wedge) on sensitivity, specificity and reliability were assessed using analysis of variance (ANOVA). Inter-examiner reliability was calculated for pairs of examiners (Cohen's Kappa) and over all examiners (intra-class correlation coefficient, ICC), and intra-examiner reliability was analysed using Cohen's Kappa. Evaluation was performed according to established quality categories. Level of significance was set at $p < 0.05$.

Results

Compared to visual-radiographic inspection, additional tactile assessment resulted in significantly increased sensitivity of detecting cavitations ($p < 0.001$, ANOVA), whilst specificity was significantly decreased ($p < 0.05$). Overall, accuracy was significantly increased when using the explorer ($p < 0.05$) (Table 1). Sensitivity and specificity increased only limitedly if gingivae were displaced; these effects were statistically not significant ($p > 0.05$). The degree of experience of the examiner did not have a significant influence on sensitivity or specificity of detecting cavitation ($p > 0.05$).

Sensitivity and specificity of detecting lesion cavitation was significantly higher for ICDAS 5 than for ICDAS 3 lesions ($p < 0.01$, ANOVA) for visual-radiographic assessment. Additional tactile assessment resulted in sensitivity being not significantly different for ICDAS 3 and 5 lesions ($p > 0.05$), whilst specificity remained significantly higher for ICDAS 3 lesions ($p < 0.05$).

Intra- and inter-examiner reliability ranged from slight to substantial agreement (Table 2). Reliability increased when tactile assessment was performed, or gingivae were displaced, but effects remained statistically insignificant ($p > 0.05$). Experienced examiners showed significantly higher intra-rater reliability ($p < 0.05$).

Microscopic evaluation of lesions revealed no cavitation after proximal probing of surfaces being assessed as non-cavitated in the initial evaluation, and only one of these 34 surfaces was found to be detectably scratched (Fig. 2).

Discussion

Declining caries prevalence in industrialised countries with associated higher fractions of earlier and less active lesions challenges established examination and treatment patterns [15, 16]. Reliable and accurate assessment of surface status of proximal lesions extending radiographically into the outer third of dentin is crucial to determine appropriate subsequent treatment [7, 16], but was shown to be difficult using mainly visual or radiographic measures [17]. Within the present study, additional tactile assessment using a thin bended 'cow-horn' explorer was found to increase accuracy and reliability of detecting cavitated surfaces.

So far, only few studies evaluated visual or visual-tactile caries detection methods in primary teeth [17–19]. Their wider contact areas presumably complicate the assessment of proximal lesions, whilst a thinner proximal enamel layer and reduced mineralisation lead to different cavitation patterns of primary compared to permanent teeth [14, 20]. Thus, successful assessment of surface integrity of proximal lesions in primary teeth is both challenging and clinically relevant.

Surface integrity is currently seen as most relevant parameter for treatment planning, since it is more difficult to remove the dental biofilm by oral hygiene measures in cavitated lesions, resulting in a significantly faster progression of such lesions [21]. Thus, correctly assessing surface integrity allows avoiding both over- and under-treatment due to false-positive and negative diagnoses. Within this study, using a thin explorer was found both helpful and feasible for such assessment. There are concerns that forceful use of so called sharp explorers, as practiced in the past for occlusal caries detection, might damage intact lesion surfaces, thus promoting lesion progression [8, 9]. In the present study, only one surface (2%) was found to be scratched, whilst the rest seemed intact after at least 12 assessments. Microscopic analysis of scratches was only performed after, but not prior to the diagnostic assessments. However, since no distinct scratches nor cavitations could be evaluated using SEM, we are convinced that the gentle probing seemed not to be harmful. This is somehow in contrast to previous studies [9, 10, 22]. However, in these, either the concept of a 'sticky probe' in occlusal fissures was evaluated [9, 22] or namely new and

Table 1 Mean ± SD sensitivity, specificity and accuracy of different methods to detect cavitated proximal lesions ($N = 46$). Assessment was performed without or with the use of rubber dam isolation and gingival displacement

	Detection method	Sensitivity (%)	Specificity (%)	Accuracy
Without rubber dam	Visual-radiographic	33 ± 8	96 ± 1	0.27 ± 0.08
	Visual-radiographic plus tactile	75 ± 7	83 ± 5	0.62 ± 0.09
With rubber dam	Visual-radiographic	51 ± 9	90 ± 2	0.42 ± 0.08
	Visual-radiographic plus tactile	86 ± 6	84 ± 5	0.65 ± 0.07

Table 2 Intra- and inter-examiner reliability (mean ± SD) for different detection and assessment methods. Inter-examiner reliability is given between pairs of examiners (Kappa) and over all examiners (ICC alpha)

	Detection method	Intra-examiner kappa	ICC alpha	Inter-examinerkappa
Without rubber dam	Visual-radiographic	0.48 ± 0.29	0.44	0.17 ± 0.24
	Visual-radiographic plus tactile	0.47 ± 0.12	0.70	0.44 ± 0.05
Withrubber dam	Visual-radiographic	0.58 ± 0.25	0.75	0.50 ± 0.09
	Visual.-radiographic plus tactile	0.66 ± 0.08	0.84	0.64 ± 0.06

sharp probes were used in a rather direct way to the occlusal or smooth surface [9, 10]. We performed our assessments with 'thin' probes having been used previously (e. g. recommended for evaluation of restoration margins) and with only gentle tactility (less than 100 g). In a clinical study, the average force used for probing of teeth in a full mouth caries examination was 340 g (SD 218 g) being slightly lower as described before [23]. However, even if this study indicates that harmful effects of proximal probing are unlikely, they cannot be ruled out completely. Thus, careful use of the explorer should be advised and sufficient training recommended.

Displacing the gingivae by using a wedge and rubber dam had no significant benefit in the present study. However, it should be noted that the absence of contact points was found useful for lesion detection proximally, which calls for the use of the technique used here (as it is easy and harmless) or the placement of orthodontic separation rings some days earlier which is necessary at least in permanent teeth [19]. Nonetheless, for primary teeth, also tooth separation for some minutes is a viable option to improve accuracy of cavitation detection proximally. Here, also a blunt or even ball-ended probe might be of value, although a recent study could not show this convincingly, which might have been due to the low proportion of cavitated lesions included in this study [19]. However, tooth separation is still considered as a rather awkward and painful method not widely being used in particular in permeant teeth. We considered our in vitro setting, using primary teeth as a model that should also reflect the situation in permanent teeth sufficiently, but this needs to be proven in the future.

Since occurrence of any cavitation in proximal lesions is commonly seen as the main decisive factor for invasive treatment [6], we did not discriminate between (deeper) ICDAS 3 from (shallower) ICDAS 5 lesions being included in the study.

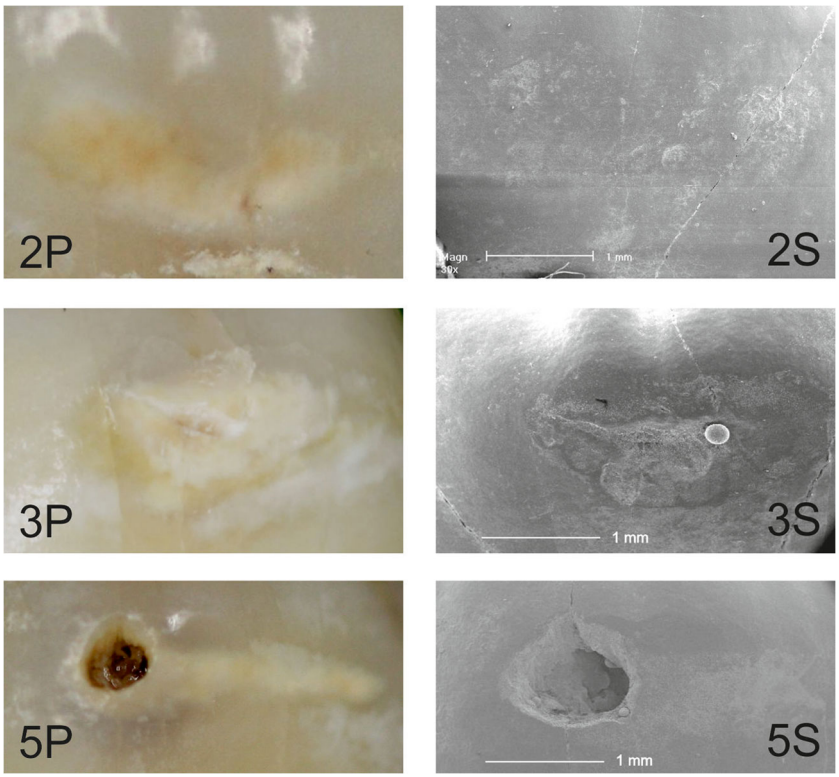

Fig. 2 Representative photos and scanning electron microscopic images of teeth with lesions according to the three ICDAS scores 2, 3 and 5 included in the study reveal no scratches. Please note the porous structure of the non-cavitated but obviously carious (photos) surface enamel in all ICDAS stages as well as the shallow cavitation in ICDAS 3 (3P and 3S) extending into dentin for ICDAS 5 (5P and 5S)

This might have been interesting when tooth separation had been performed which was not included due to the rationale of the study focusing on a pragmatic proximal caries assessment.

Within the present study, no magnification aids were used for visual examination. Magnification, for example using loupes, has been shown to be able to improve sensitivity of detecting caries lesions [24], or to not improve accuracy but to decrease reliability [25]. Since visual detection of proximal cavitation without separation of teeth is likely to yield only limited accuracy, the use of loupes or microscopes was not expected to have substantial benefit for lesion assessment in the present study.

Examiners within this study evaluated the same lesions for in total four times. Thus, a learning effect is theoretically possible. However, the analysis of repeated measurements 1 week after the first examination did not confirm such effects. It can be speculated that the number of evaluated lesions and the time between the examinations was sufficient to avoid memorising exact lesions and their extension. The same holds true for the initial visual screening by one of the evaluators. Moreover, a single experienced clinician (HML) performed the selection of the 46 study teeth only.

The assessment of radiographs before visual and visual-tactile evaluation, however, presumably allowed pre-assessment of the lesions extension, and thereby might have increased the accuracy of detecting surface cavitation. This, however, reflects clinical reality within the described screening process, and was thereby welcomed.

Translating the findings of this in vitro study into clinical practice and for permanent teeth should be performed with caution given the limited number of examiners and the performed assessment of extracted primary teeth only. However, the distribution of lesions in the present study followed real-life prevalence, and positive and negative predictive values may therefore reflect clinical reality as far such reality exists. The performed validation using ICDAS can be expected to have high validity and reliability [26]. The lack of power due to limited sample sizes should be considered when discussing the absence of statistical significance for certain analyses (influence of experience, effect of gingiva displacement).

Conclusions

In conclusion, the gentle use of a fine bended explorer to assess proximal caries lesions in primary molars increased both validity and reliability for the decision regarding surface cavitation in vitro. Displacing the gingiva resulted in no statistically significant improvement. Detrimental effects of probing on surface integrity seem unlikely if examiners are sufficiently trained. Within the limitations of this study, proximal probing was found a useful additional diagnostic tool.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The use of the teeth was ethically approved (D444/10).

Informed consent Informed consent for the use of the teeth was provided under the ethics approval D444/10.

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