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ORIGINAL ARTICLE

The anatomy of non-carious cervical lesions

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Abstract
Objective The term “non-carious cervical lesion” (NCCL) describes a dental hard tissue defect of unknown origin. Two very distinct variations are known: wedge-shaped and saucer-shaped lesions. Reasons for occurrence of two forms might include different contributing factors.
Methods Forty-two teeth, 19 wedge-shaped and 23 saucer-shaped lesions, were analysed by light and confocal laser scanning microscopy (CLSM) to investigate presence of calculus and organic matter, surface structure of the lesion, borders of the lesion, and potential fractures in the dental hard tissues.
Results One hundred percent of the wedge-shaped teeth showed evidence of additional abrasion (incisal/occlusal surface) but only 70 % of the saucer-shaped teeth. In most teeth, the edge was rounded. Tiny grooves parallel to the cemento-enamel junction (CEJ) were present in 11 % of the wedge-shaped and in 39 % of the saucer-shaped lesions. Seventy-nine percent wedge-shaped and 52 % saucer-shaped lesions had some sort of apposition. Eighty-eight percent of all teeth had dead tracts, 62 % of which were located directly next to the defect (in the lesion). In 48 %, sclerotic dentin was present right next to the defect (in the lesion). Tertiary dentin was visible in 60 %. Not a single fracture was detected.
Conclusion Different characteristics associated with each type of cervical lesion support the theory of different aetiology or at least of differing contributions from different factors that participate in the development of NCCLs.
Clinical relevance Only knowledge of the correct aetiology of NCCLs will allow the best treatment and prevention for such lesions.

Keywords Non-carious cervical lesion · Abrasion · Abfraction · Erosion · Occlusal wear

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Introduction

The term “non-carious cervical lesion” (NCCL) describes the loss of hard dental tissue at the cemento-enamel junction (CEJ) without caries decay (Fig. 1). According to Eccles, the dental hard tissue loss is separated into three classes [1] (Table 1).

Historically, three different anatomical variations of the CEJ have been described: in ~60 %, the cementum overlaps the enamel; in ~30 %, there is an edge to edge relationship; and in ~10 %, the enamel and the cementum fail to touch with a consecutive small area of exposed dentin. The variation with enamel-covered cementum also has been described [2, 3]. All these variants can appear at the same tooth.

The CEJ is a very vulnerable region, since cementum and dentin are not very resistant to environmental impact, and the enamel itself only forms a very thin layer in this region. Amongst other things, this specific anatomical feature might be responsible for occurrence of NCCL, especially in older

Fig. 1 Non-carious cervical lesion at a molar at the cementum–enamel junction

adults due to a higher prevalence of gingival recession and root exposure [4].

The first defect at the CEJ was described in 1931 [5]. Since then many articles have been published contributing to this topic using terminology such as erosion or abfraction. These terms imply a specific aetiology of the NCCL although the exact aetiology is not fully understood [6]. The most common theory favours a multi-factorial causality. Several theories regarding the development of NCCL are being discussed [7]. The cervical region is the most vulnerable part of the tooth, since the enamel is of poorer quality with a higher pore volume, protein content and a lower mineral content. Further, factors might be an abrasive damage caused mainly by oral hygiene, erosion caused by low pH values of non-bacterial origin, such as drinks and stomach acid. Other theories describe dysfunctional loading of the teeth, e.g., due to parafunctions or neuro-muscular disorders with a possible tensile stress on the cervical region. In addition, a possible piezoelectrical effect of the dentin with a possible attraction of active ions in erosive agents was postulated. Composition and quantity of saliva might contribute. High flow rates might be protective saliva with a high content of citric acid and a lower buffer capacity might promote the development of NCCL [7]. Possible contributing factors are erosion, abrasion and abfraction [6], the last very often being associated with a simultaneous attrition [8].

Table 1 Classification of dental hard tissue loss according to Eccles [1]

Class	Description	
I	Superficial lesion, limited to the enamel only	
II	Localized lesion, involvement of dentin in less than 1/3	
III	Generalized lesion, involvement of dentin in more than 1/3	
	A	Facial surfaces
	B	Lingual and palatal surfaces
	C	Incisal and occlusal surfaces
	D	Severe multi-surface involvement

Erosion describes chemical destruction of hard dental tissue due to acids [9], whereas abrasion describes mechanically induced loss of hard tissue, e.g., due to tooth brushing [10]. The term “abfraction” is used to describe breakdown of the dental hard tissue at the CEJ caused by non-axial load on the tooth leading to a cusp flexure with a stress peek at the CEJ that might cause the NCCL [6]. Attrition is the physiological loss of dental hard tissue due to tooth-to-tooth contact.

Two very distinct shapes of NCCL can be observed: a wedge-shaped (Fig. 2) and a saucer-shaped lesion (Fig. 3). Next to those, mixed shaped lesions can be observed. It can be speculated that different mechanisms or their combinations may form the basis of the different shaped lesions.

In the case of erosion or abrasion, the surface of the NCCL should be very smooth. In addition, in cases caused mainly by abrasion, the surface should lack a thick layer of plaque or calculus due to constant mechanical removal. In the hypothetical case of abfraction, small fractures should be visible at the surface of the NCCL because the non-axial load and the resulting stress at the CEJ might result in small fractures leading to the breakdown of the dental hard tissue.

The following study pursued two goals: the detection of potential structural abnormalities in teeth with NCCL depending on the shape of the NCCL and the detection of organic matter and calculus in the area of the NCCL.

Fig. 2 Wedge-shaped lesion with a concave coronal-shaped surface and an apical convex-shaped surface of the defect

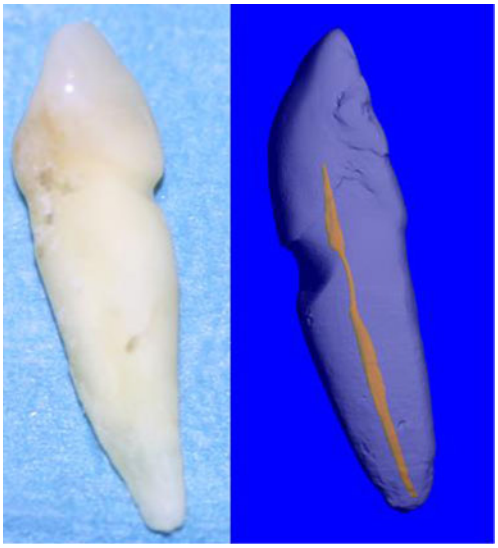

Fig. 3 Saucer-shaped lesion. *Picture on the right-hand side* taken with the SCANCO μCT 40. The *string in the middle* represents the endodontic channel that has a narrow passage corresponding to the NCCL representing an indirect proof of tertiary dentin

Materials and methods

A series of teeth were extracted, fixed in formalin and examined for NCCL. All together, 42 teeth with either a typical wedge-shaped or saucer-shaped lesion were identified (16 lower incisors, 15 upper incisors, five lower premolars, four upper premolars and two upper molars). Twenty-three teeth had a saucer-shaped and 19 had a wedge-shaped lesion.

All teeth were dehydrated and embedded in Technovit 7200 (Kulzer, Wehrheim Germany), and the blocks were cut along the axis of the tooth in oro-vestibular direction so that the resulting blocks both had half of the NCCL. One 300-μm-thick slice for light microscopy was obtained.

All slices were analysed with a Leica CTRMIC light microscope at different magnifications. In addition, all blocks were scanned by confocal laser scanning microscopy (CLSM) (Leica CLSM TCS SP2 X1) along the defect surface obtaining a better resolution, and some blocks were analysed by a scanning electron microscope (FEI Quanta 200 FEG).

The following details were analysed for all lesions: calculus or organic matter on the NCCL, surface of the lesion (smooth or rough), exact border of the lesion (edged or smooth), structure of the dentin and potential fracture lines in the dental hard tissue. Furthermore, wedge-shaped defects were analysed regarding the very tip of the lesion (round or pointed), the surface of the lesion (concave, convex) and the relation to the direction of the dentin tubes.

To determine statistically significant differences between two variables, the Chi-Quadrate test was used, and in cases of less than five counts in one group, the Fisher's exact test. A p value <0.05 was considered significant. For smaller sample sizes, the statistics were restricted to a descriptive analysis only.

Results

In total, 42 teeth were analysed: 23 teeth with a saucer-shaped lesion (Fig. 4) and 19 with a wedge-shaped lesion (Fig. 5).

Attrition

Of the 42 teeth, 35 (83 %) had an additional attrition at the incisal edge/occlusal surface. Nineteen (54 %) of those had a wedge-shaped lesion and 16 (46 %) a saucer-shaped lesion, resulting in an additional attrition in 100 % of the teeth with a wedge-shaped and 70 % with a saucer-shaped lesion. Seven teeth had no additional attrition, and they all had a saucer-shaped defect (p=0.009).

Border of the defect

Four different groups could be detected. The most common case was a rounded border both at the coronal and the apical borders of the defect (19 out of 42: 45 %). The coronal rounded, apical-edged border was the second largest group (11 out of 42: 26 %). The third largest group had coronal-edged and apical-rounded borders (nine out of 42: 22 %). The last group had an edged border at both sides (three out of 42: 7 %).

The borders were rounded in 14 (61 %) out of the 24 saucer-shaped NCCL teeth but only in five (26 %) out of 19 with a wedge-shaped lesion. Sharp edges at both borders could be seen in two lesions with a wedge-shaped lesion and in one saucer-shaped lesion. Eight (35 %) out of 23 saucer-shaped and 12 (63 %) out of 19 wedge-shaped lesions had one edge and one rounded border (Table 2). There was no statistically significant difference in the distribution (p=0.063).

Surface of the defect

The surface of the defect was found to have an additional ultrastructure in two of the 19 teeth with a wedge-shaped defect in the form of tiny grooves running parallel to the CEJ. Such grooves were visible in nine out of 23 (39 %) teeth with a saucer-shaped lesion (p=0.038; Table 1).

Appositon at the site of the defect

Twenty-seven out of 42 teeth (64 %) had some sort of apposition. Fifteen out of 19 (79 %) with a wedge-shaped and 12 out of 23 (52 %) with a saucer-shaped lesion (p= 0.062; Table 1) demonstrated some sort of apposition. In six cases (15 %), the apposition was only visible in the fluorescent scanning mode and not in light microscopy (Fig. 6).

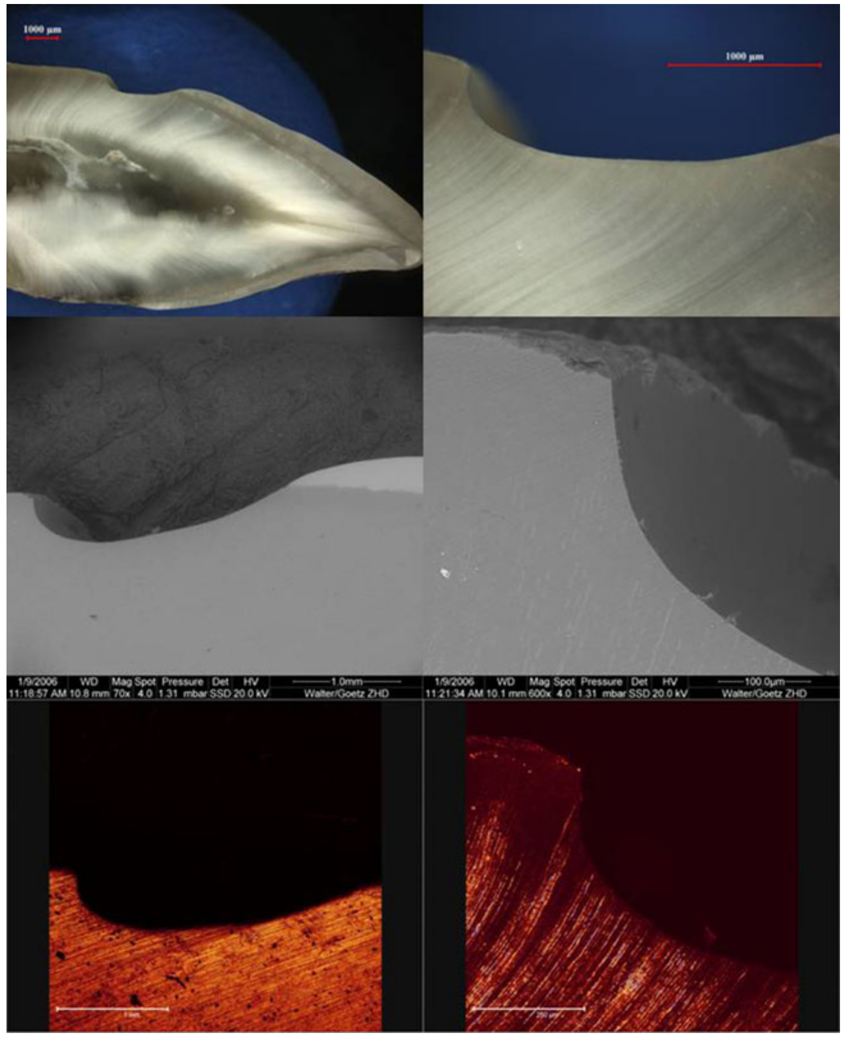

Fig. 4 Composition of light microscopy (*top*), scanning electron microscopy (*middle*), and confocal laser scanning microscopy (*bottom*). Saucer-shaped lesion. A smooth surface without any plaque is visible in all pictures. The surface of the root does not seem as smooth as the surface of the lesion itself as it is displayed in the scanning electron microscope pictures. In the higher magnification of the confocal laser scanning microscopy, the dentin structure is clearly visible

Dentin structure

In most cases, the dentin showed abnormalities. In 37 out of 42 teeth (88 %), dead tracts could be found. In 23 of those teeth (62 %), the dead tracts were located directly next to the defect in the area of the lesion. In all those cases, tertiary dentin was visible. Of the 42 teeth, 26 had sclerotic dentin, and all of those teeth had dead tracts. In 20 of those teeth, the sclerotic area was situated next to the defect. In three teeth, no observation in this area was possible due to artificial changes. Tertiary dentin was visible in 25 out of the 42 teeth (59.5 %). In 14 cases, this region is artificially changed; therefore, an analysis was not possible. In only three cases (7 %) was no tertiary dentin present.

Fractures

There were no fractures visible at any resolution in the light microscopy and the CLSM.

Wedge-shaped lesions

The apical and the coronal surfaces of the wedge-shaped lesion can have several forms: convex, concave and straight (Fig. 2). The five detected combinations are summarised in Table 3.

The apical surface of the lesion extended perpendicularly to the direction of the dentin tubuli (nine out of 42: 21 %) or perpendicular to the axis of the tooth (eight out of 42: 19 %). In one case, the surface was parallel to the dentin tubuli, and in one case, there was no special orientation of the surface in relation to other anatomical structures. In 12 out of 19 cases (63 %), there was an acute angle; in six cases (32 %), there was a right angle, and in only one case, there was an angle of more than 90°.

Scanning electron microscopy

Five blocks were additionally analysed for fractures with scanning electron microscopy (SEM) (Fig. 7). In

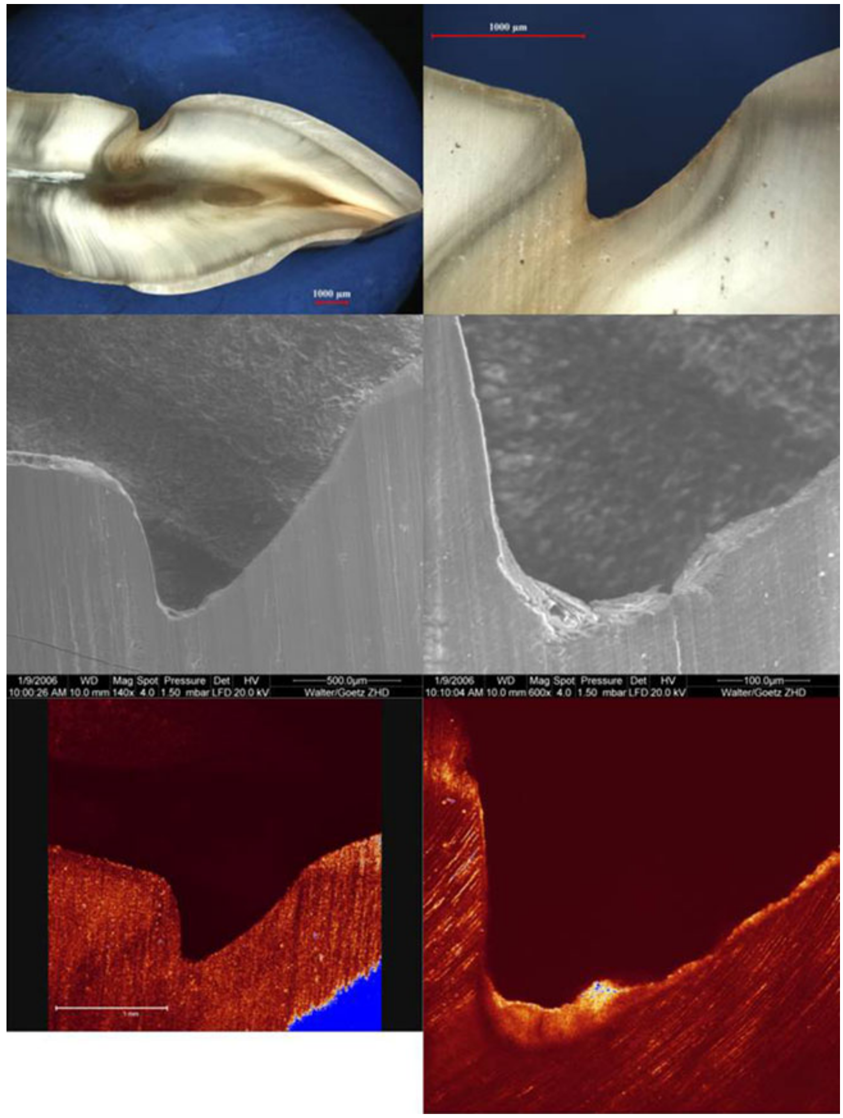

Fig. 5 Composition of light microscopy (*top*), scanning electron microscopy (*middle*), and confocal laser scanning microscopy (*bottom*). Wedge-shaped lesion with an altered dentin colour in the light microscopic picture. The plaque at the tip of the defect, which is hardly visible in the lower magnifications of the light microscopy is easily detectable in the scanning electron microscopy and the confocal laser scanning microscopy. Possible fractures of the dentin at the tip of the defect cannot be excluded for sure due to the plaque in the scanning electron microscopy. The dentin tubuli can be followed right up to the surface of the lesion so that a fracture seems to be unlikely

four of five cases, fracture lines were visible. Those fracture lines ran from the tooth into the embedding material and therefore, were considered artificial fractures (Fig. 8).

Table 2 Characteristics of the wedge- and saucer-shaped lesions

	Wedge-shaped lesion (*n*=19)	Saucer-shaped lesion (*n*=23)
Shape of the edge		
Both rounded	5 (26 %)	14 (61 %)
One rounded, one edged	12 (63 %)	8 (35 %)
Both edged	2 (11 %)	1 (4 %)
Grooves on the surface	2 (11 %)	9 (39 %)
Apposition	15 (79 %)	12 (52 %)
Attrition	19 (100 %)	16 (70 %)

Discussion

The aetiology of NCCL is not well understood, but a multifactorial basis is generally accepted [6, 8]. The occurrence of different distinct shapes of NCCL has led to the theory of different quantitative contributions of the different mechanisms as a topic of discussion in the genesis of NCCL. The aim of this study was to detect structural differences between the wedge-shaped and the saucer-shaped NCCL that might support this hypothesis.

The appearance of attrition was seen in all teeth with a wedge-shaped lesion and 70 % of the teeth with a saucer-shaped lesion. A corresponding relationship between attrition and NCCL has been assumed by several authors [11, 12]. Many research groups have focused on occlusal forces and the different shear stresses developing in enamel and dentin [13]. Occlusal forces are higher in patients suffering

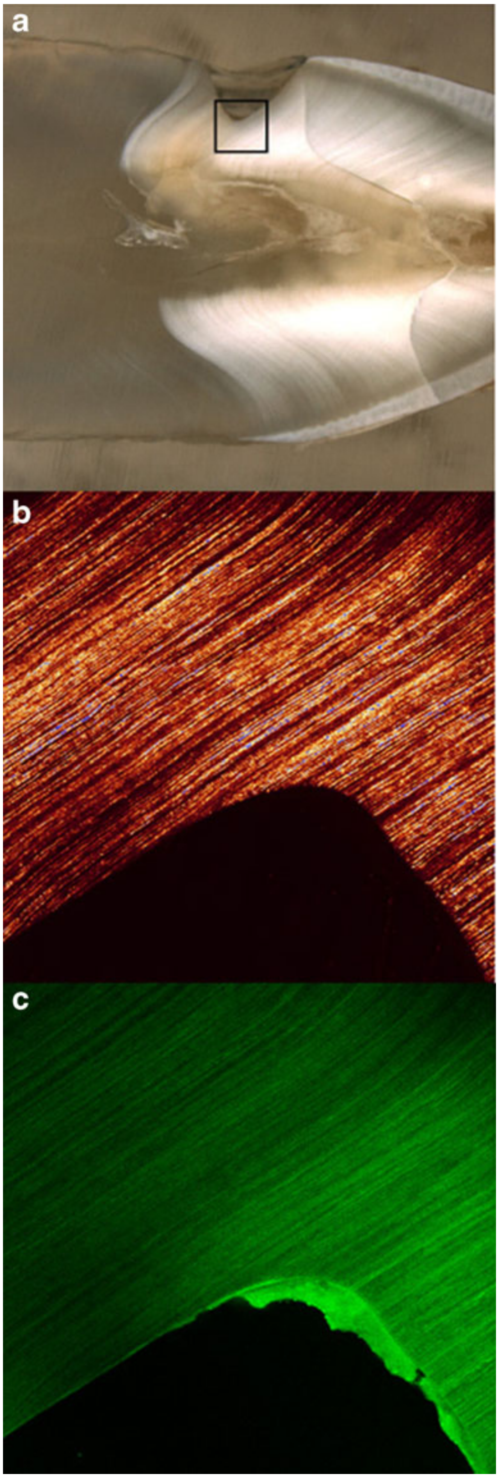

Fig. 6 Wedge-shaped lesion displayed with light microscopy (**a**) with confocal laser scanning microscopy (**b** and **c** [fluorescent mode]) at a magnitude of ×50. The apposition is clearly visible in the fluorescent mode

from bruxism than in patients without bruxism. A typical clinical sign in these patients is attrition. The forces result in

Table 3 Distribution of the curvature of the coronal and apical surface of the wedge-shaped lesions

Coronal Apical	Concave	Straight	Convex
Convex	11 (58 %)		
Straight	2 (10.5 %)	2 (10.5 %)	
Concave	2 (10.5 %)		2 (10.5 %)

stress build up in enamel and dentin [13]. The CEJ can be considered a higher risk area where the process of abfraction might start.

Abfraction is defined as the hard dental tissue loss due to non-axial tooth loading With regard to this theory, the occurrence of micro-fractures at the site of the NCCL is feasible. However, no fractures could be detected in the wedge-shaped or saucer-shaped lesions with either the light microscope or the CLSM. Only the SEM revealed fractures that were most probably artefacts, since most of them continued into the embedding material or were situated at the edge of the split line, likely due to the sawing machine. It has been hypothesised that once single bonds between hydroxyapatite crystals are broken, water or other small molecules may penetrate these, and re-bonding between the hydroxyapatite crystals is inhibited. This altered dental structure may be more susceptible to other damaging factors such as erosion and abrasion [14–16]. Such small lesions

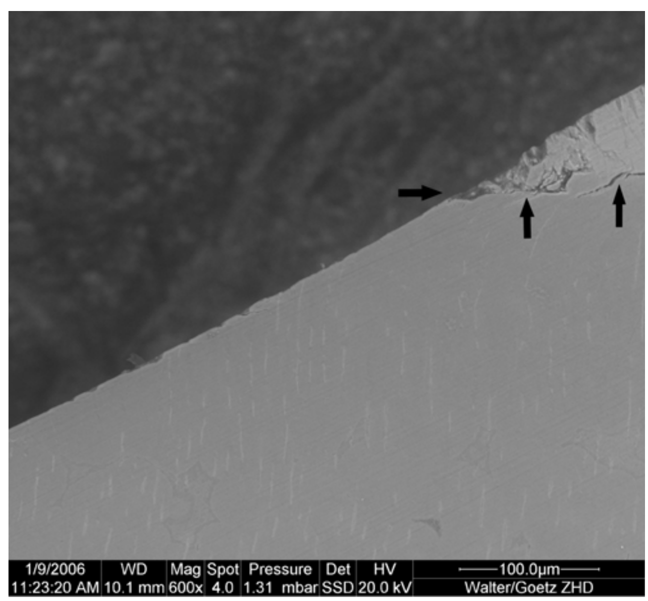

Fig. 7 Multiple small fractures at the surface of the defect (*arrows*) most probably artificial due to the sanding of the block. The *arrow on the right-hand side* points out the loosening of the enamel from the underlying dentin

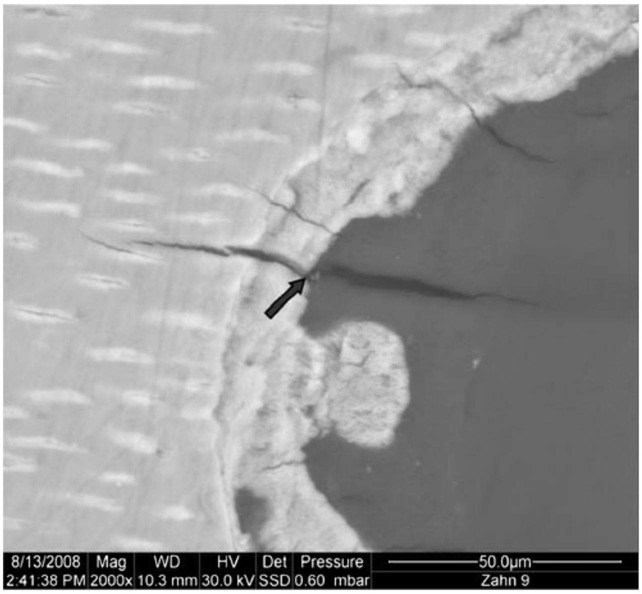

Fig. 8 Artificial fracture at the surface of the defect running from the dental hard tissue into the embedding material

may be too small to be detected with common optical devices. Presence of different shaped lesions and varying distribution of attrition could be an indicator of the impact of attrition on the shape of the lesion.

Although not statistically significant (p=0.062), plaque did appear more often on teeth with a wedge-shaped lesion. This aspect should not be overestimated since this might only be a momentary situation at the time of extraction. Lesions caused by abrasion due to tooth brushing would be more likely to have no plaque. In contrast, chemical degradation of the surface caused by plaque and bacteria might weaken the CEJ and make it more susceptible to further damage [17]. This could be influenced by further factors such as low pH values [7].

The higher percentage of plaque in teeth with wedge-shaped lesions makes the abrasion theory less likely. If the lesion was caused by vigorous oral hygiene, less plaque would be expected. A higher prevalence of plaque in wedge-shaped NCCL compared to adjacent teeth has already been described. A plausible explanation is that the lesion itself is not exposed to the bristles of the toothbrush [4]. This would support the idea of a higher contribution of abrasion in saucer-shaped lesions compared to wedge-shaped lesions. Attrition might be a major factor in wedge-shaped lesions, whereas abrasion might only play a minor role.

Additional occurrence of grooves parallel to the CEJ could support the theory of tooth brush abrasion in saucer-shaped lesions, since they were detected nearly four times more often in saucer-shaped lesions than in wedge-shaped lesions in this study. Another article analysed small furrows with a size between 5 and 250 μm. They were discerned into horizontal smooth furrows as a sign of erosion and smaller horizontal scratch marks as a sign of abrasion [18].

The border of the defect was more often rounded in the saucer-shaped lesion that could be due to erosion and tooth brushing, whereas the borders of the wedge-shaped lesion were more often edged, since a possible fracture would be associated with a sharp edge. In a recently published article, 50 teeth were analysed by micro-computed tomography. In all cases, the defect was located below the CEJ in the area of the root with a sharp enamel margin, which was interpreted as an intact CEJ. Due to this fact, the authors did not see any association to the abfraction theory, since this would result in a blunt margin [19]. However, this fact could indeed support the abfraction theory. The non-axially loaded and stiffer enamel crown could cause the hard dental tissue damage below the CEJ, since the elastic modulus of enamel is notably higher than that of dentin [13].

An obvious association of the arrangement of the dental structure elements and the shape of the lesion can be seen in the orientation of the defect. For instance, the two surfaces of the wedge-shaped lesion had a characteristic orientation either perpendicular or parallel to the dentin tubuli according to the typical fracture behaviour that is usually perpendicular or parallel to the dentin tubules. Enamel, in contrast, more often fractures parallel to the enamel rods [20].

In conclusion, this study failed to detect the expected micro-fractures in the wedge-shaped lesions. The simultaneous occurrence of attrition and presence of plaque in most of the wedge-shaped lesions in comparison to the saucer-shaped lesions might be an indicator of a possible greater contribution of abfraction in wedge-shaped lesions, if there is any. Based on the findings of this study, more sensitive methods should be used to detect micro-damage in the dental hard tissues. A big confounder in such in vitro analyses is the induction of additional damage whilst extracting the teeth, during preparation of the teeth and during the analysis itself.

Future studies analysing teeth with similar methods might correlate further aspects with their results such as vitality of the teeth at the time of extraction, since it might have an impact on the reaction of dentin in terms of producing sclerotic material. Individual oral hygiene aspects could be taken into account as well.

Large prospective clinical studies might have the power to detect associations between abrasion, attrition, erosion and corrosion with the NCCL. This is of interest as it might influence the therapy of NCCL [21–26] and especially prevention of NCCL [27].

Conflict of interest None.

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