

A qualitative assessment of non-carious cervical lesions in extracted human teeth

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ABSTRACT

Background: Opinions vary about the causes of non-carious cervical lesions (NCCLs). They have been attributed to toothbrush abrasion, acid corrosion (commonly termed dental erosion), and abfraction. The purpose of this study was to examine the microwear details of NCCLs in a collection of extracted human teeth using scanning electron microscopy (SEM).

Methods: Negative replicas of large NCCLs in 24 extracted human teeth were obtained in polyvinylsiloxane impression material (Light Body Imprint™II, 3M ESPE) and viewed under SEM.

Results: All NCCLs extended from the cemento-enamel junction to the root surface and they displayed a variety of wedge-shaped appearances. There was evidence of both abrasion and corrosion in 18 of the 24 teeth (75.0 per cent), abrasion only in one tooth (4.2 per cent) and corrosion only in five teeth (20.8 per cent). Horizontal furrows with smooth edges and minor scratch marks, characteristic of abrasion and corrosion, were noted in 13 teeth (54.2 per cent).

Conclusions: Based on microscopic assessment of a sample of extracted teeth, it appears that abrasion and corrosion are common associated aetiological factors in the formation of NCCLs.

Key words: Abrasion, erosion, abfraction, scanning electron microscopy.

Abbreviations and acronyms: CEJ = cemento-enamel junction; FEA = finite element analysis; NCCLs = non-carious cervical lesions; SEM = scanning electron microscopy.

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INTRODUCTION

The term non-carious cervical lesion (NCCL) refers to the loss of tooth structure at the cemento-enamel junction (CEJ) of teeth by wear processes unrelated to bacterial action.¹ NCCLs can present in a variety of forms, including shallow grooves, broad saucer-shaped lesions and large wedge-shaped lesions.¹ It has been reported that NCCLs occur in up to 85 per cent of individuals, with their prevalence and severity increasing with age.² Large NCCLs with exposed dentine can cause dentine hypersensitivity^{3,4} and increase the risk of pulp exposure or tooth fracture.⁵

There are numerous theories regarding the aetiology of NCCLs, including toothbrush abrasion, corrosion (commonly termed dental erosion) and abfraction,^{1,6–8} and this has led to confusion over their management. Recommended treatment options include monitoring, adhesive restorations, diet modification, tooth cleaning regimes, and even occlusal adjustment to prevent further progression.^{5,9} Toothbrush abrasion has been

considered to be a cause of NCCLs since the mid-twentieth century,^{1,5} but McCoy¹⁰ proposed that bruxism had a primary aetiological role. The abfraction hypothesis states that concentration of tensile forces at the cervical region of teeth, as a result of cuspal flexure from heavy occlusal loading, leads to micro-crack formation cervically by disrupting bonds between hydroxyapatite crystals in enamel and dentine.^{10,11} These cracks are then believed to be further susceptible to abrasion and corrosion.¹² However, there is a general lack of firm clinical evidence to support the abfraction hypothesis, and non-clinical models supporting this remain unrealistic.¹³ In this context, assessment of microwear details of NCCLs may provide some insight into their aetiology.

Detailed studies investigating microwear features of NCCLs are scarce. A previous study using scanning electron microscopy (SEM) described the morphology of NCCLs at a magnification of $\times 15$, and the authors suggested that the wedge-shaped lesions might have been caused by abfraction.¹⁴ In another investigation

conducted on six individuals, Bevenius *et al.*¹⁵ noted horizontal or oblique scratches and grooves of varying depth and regularity in both saucer- and wedge-shaped NCCLs. The authors stated that the NCCLs were of idiopathic origin, although they noted horizontal scratch marks in enamel and dentine that were characteristic of abrasion.³ In contrast, corrosion results in a much smoother appearance of the tooth surface, with enamel displaying honeycomb structures¹ and dentine displaying an undulating or rippled surface at a high magnification.¹⁶ Abrasion and corrosion occurring in combination produce a smoother dentine surface compared with abrasion alone.⁴ Although the detailed micromorphology of abfraction lesions remains unclear, an *in vitro* study noted fracture and chipping of enamel in the cervical region of premolar teeth subjected to occlusal stress under neutral and acidic conditions.⁸

By examining the microwear details of NCCLs in a collection of extracted human teeth, we aimed to clarify the nature of the factors involved in their aetiology.

MATERIALS AND METHODS

Twenty-four extracted human teeth with large cervical lesions were selected from a collection of teeth extracted as part of general dental treatment at the Adelaide Dental Hospital. The protocol for collection of extracted teeth was approved by The University of Adelaide Human Ethics Committee (H/27/90). These teeth had been stored in Savlon, an antiseptic agent, which complied with infection control practices at the Adelaide Dental Hospital.

After the teeth were gently handwashed with water and air-dried, extraneous material from the NCCLs was removed by obtaining impressions in alginate (3M ESPE Palgat™ Plus Quick, Seefeld, Germany), as described in a previous study.¹⁷ The NCCLs were then categorized as wedge-shaped or scooped lesions by visual examination. Negative replicas of the NCCLs were obtained using polyvinylsiloxane impression material (3M ESPE Imprint™ II Garant™ Light Body, St Paul, USA), and then examined under SEM at various magnifications. Each NCCL was examined for presence of abrasion and corrosion in nine different fields or regions, except when they were obscured by artefacts. To determine whether there was any major variation in the micromorphology in different regions of the NCCLs, each lesion was divided into upper, middle and lower thirds and also into mesial, central and distal thirds. The nine fields were examined for each specimen to determine whether there was evidence of abrasion only, corrosion only, or a combination of both. Representative micrographs showing evidence of abrasion, corrosion or a combination of both were selected for presentation in this report. The NCCLs

examined did not display evidence of damage as a result of extraction. Replication of microwear details from natural teeth into silicone rubber impressions and epoxy dyes has been validated at a resolution of less than 1 µm in a previous study.¹⁸

RESULTS

The NCCLs were all on buccal surfaces and extended from the CEJ to the root surface. They displayed a variety of appearances (Fig 1). There was no major variation in the micromorphology observed across all nine fields of each NCCL. All lesions showed evidence of abrasion and/or corrosion. Using SEM, abrasion was characterized by the presence of horizontal scratch marks (Fig 2) while corrosion was characterized by a smooth surface (Fig 3). When both abrasion and corrosion occurred in combination, scratch marks (Fig 4) were not as pronounced as those produced by abrasion only (Fig 2).

There was definite evidence of both abrasion and corrosion in 18 of the 24 teeth (75 per cent), abrasion only in one tooth (4.2 per cent) and corrosion only in five teeth (20.8 per cent) (Table 1).



Fig 1. Variation in the appearance of non-carious cervical lesions (NCCLs) that extend from the cemento-enamel junction (CEJ) to the subjacent root surface in a mandibular right lateral incisor (a) and in a mandibular left central incisor (b).

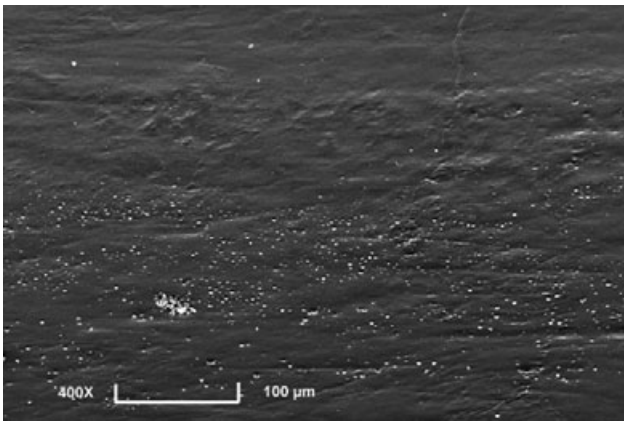


Fig 2. A micrograph showing evidence of abrasion within an NCCL characterized by presence of parallel horizontal scratch marks ($\times 400$ magnification). The white spots are artefacts, produced by scattering of electron beams incident on the irregular surface of the NCCL.

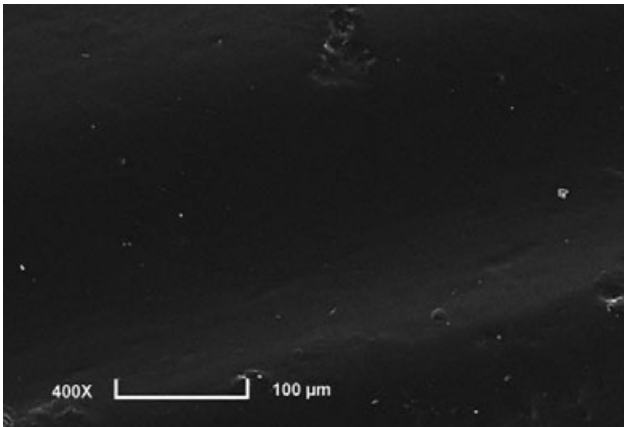


Fig 3. A micrograph showing evidence of corrosion in dentine within an NCCL characterized by smooth surface ($\times 400$ magnification).

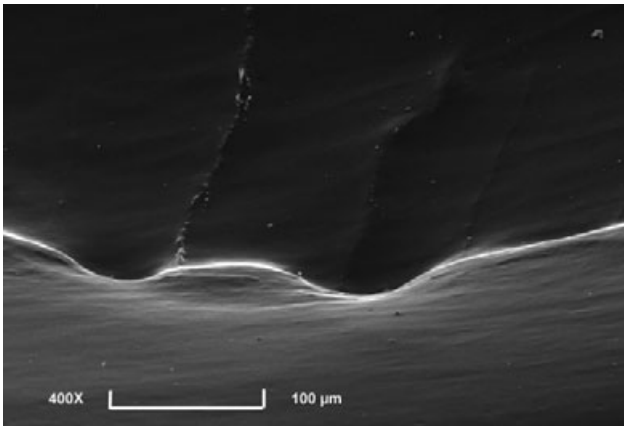


Fig 4. A micrograph showing evidence of abrasion and corrosion occurring concurrently in an NCCL ($\times 400$ magnification). The wavy line at the centre of the micrograph represents the upper margin of the NCCL, and horizontal scratch marks in the NCCL (below the wavy line) appear relatively smoother.

Horizontal furrows were noted in 13 (54.2 per cent) teeth. Their widths varied considerably from around 5–250 µm, and some of them ran mesio-distally almost

Table 1. Summary of wear characteristics of non-carious cervical lesions (NCCLs)

Wear characteristic	Number of teeth	Per cent (%)
Both abrasion and corrosion	18	75.0
Abrasion only	1	4.2
Corrosion only	5	20.8
Total	24	100.0

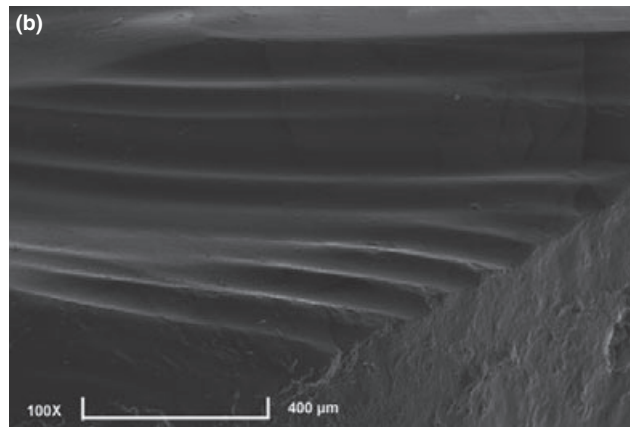
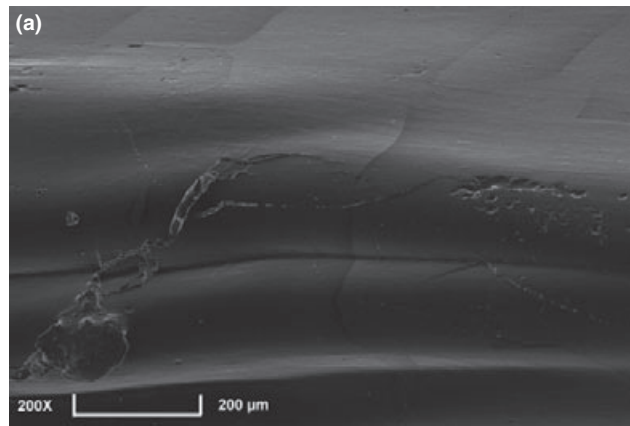
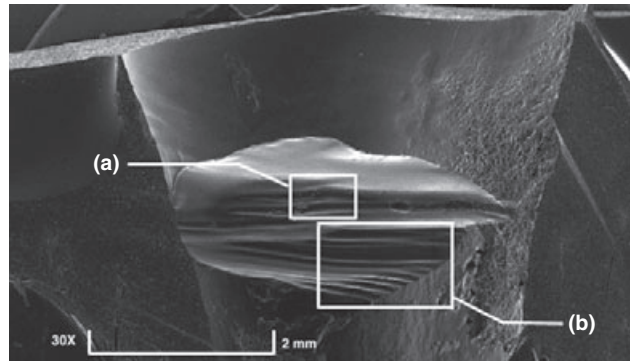


Fig 5. A micrograph of an NCCL showing numerous horizontal furrows at a magnification of $\times 30$. Enlarged areas of this micrograph are shown in (a) and (b). Horizontal furrows in (a) are around 100–250 µm wide ($\times 200$ magnification) and those in (b) are around 20–100 µm wide ($\times 100$ magnification). Minor horizontal scratch marks towards the top-half of the micrograph (a) are characteristic of both abrasion and corrosion occurring concurrently. There are some artefacts on the lower left part of micrograph (a). Horizontal furrows in (b) appear smooth, which is characteristic of corrosion.

along the entire length of the NCCLs. The horizontal furrows generally appeared smooth, characteristic of corrosion, but minor horizontal scratch marks were also noted to occur adjacent to these furrows, indicating a combination of abrasion and corrosion (Fig 5).

DISCUSSION

Although several wedge-shaped NCCLs with sharp internal line angles were observed in the present study, a detailed classification of different morphological forms was not undertaken. A separate study is being conducted by our research group to develop a detailed classification system for NCCLs according to their morphological forms and to associate these with aetiological factors. Evidence of abrasion and/or corrosion was noted in all NCCLs in the present study, but extensive crack networks that would be expected in abfraction-induced NCCLs were not found. However, some researchers have implied that such crack networks may occur only on cervical enamel.^{19–21} Crack networks on the cervical enamel, as described by Palamara *et al.*,⁸ need to be verified clinically before the abfraction hypothesis can be validated. In another *in vitro* study, artificial NCCLs produced in extracted premolar teeth under axial loading in an acidic environment had rounded outlines similar to those formed *in vivo*.²² Micrographic assessment of these NCCLs revealed an extensively corroded enamel, cracks in dentine coronal to the NCCL, concentric steps extending from the outer surface towards the centre and an extensively “rippled” appearance of the dentine surface.²² These features were not found in any of the NCCLs in this study or in previous *in vivo* studies.^{15,18} This implies that considerable caution is needed when extrapolating findings based on artificial NCCLs to the clinical situation.

The present study also provides a comprehensive description of horizontal furrows. These are less pronounced than the concentric steps or deep grooves described in artificial NCCLs.^{22,23} One previous *in vivo* study has presented micrographs of NCCLs showing horizontal furrows but does not provide any explanation.¹⁵ In the present study, a large proportion of NCCLs (54.2 per cent) displayed evidence of horizontal furrows of varying sizes. We propose that smaller furrows (5 µm in width) may coalesce to form larger ones (up to 250 µm in width), and that this process continues to further increase the size of NCCLs. The streamlined or smooth appearance of horizontal furrows, with few scratch marks, suggests involvement of both abrasion and corrosion in their formation, although corrosion is more likely to be a predominant wear process.

Litonjua *et al.*²³ noted in their *in vitro* study that toothbrush abrasion began apical to the CEJ,

progressed to dentine, and then undermined cervical enamel. These findings are supported by our observation that NCCLs extended from the CEJ to the root surface (Fig 1). In contrast, the abfraction hypothesis states that cervical enamel is the initial site of progression of NCCLs, and that tensile forces generated by cuspal flexure result in microfractures of enamel and dentine crystals in the cervical region.¹¹ This hypothesis provides an explanation for possible mechanisms involved in the breakdown of hydroxyapatite crystals in cervical enamel where enamel crystals are aligned approximately perpendicularly to the dentino-enamel junction.²⁴ However, the majority of hydroxyapatite crystals in dentine are orientated in a different direction, approximately perpendicular to the long axis of dentinal tubules. Dentine also contains areas of randomly orientated crystals.²⁵ The abfraction hypothesis does not provide any explanation about how wedge-shaped NCCLs can form by breakdown of hydroxyapatite crystals in dentine. It seems likely that tensile stresses acting on teeth may have different effects on enamel and dentine.

The abfraction hypothesis is based primarily on computerized models of finite element analysis (FEA),^{19–21} but most FEA models do not incorporate periodontal ligament or alveolar bone. A few models incorporating these structures have provided some support for the abfraction hypothesis,^{19,26} whereas others have indicated that periodontal tissues are likely to dissipate occlusal forces from the cervical area.²⁷ Most researchers have modelled enamel, dentine, periodontal ligament and alveolar bone as structures having identical physical properties in all planes (isotropic) rather than structures having different physical properties in different planes (anisotropic).^{20,21} Using an FEA model, it has been shown that anisotropic enamel structure dissipates tensile stress in the cervical region of teeth more effectively than an isotropic structure.^{28,29} Thus, the effect of tensile forces on the cervical region of teeth in most FEA models may not accurately depict the actual clinical situation.^{2,30} Further research is needed to clarify whether modelling of dentine as an anisotropic structure in FEA leads to reduction in cervical strain and plastic deformation of teeth due to occlusal loading.

Only a few *in vitro* studies have investigated factors responsible for the formation of artificial NCCLs.^{22,23} Whitehead *et al.*²² reported that artificial NCCLs formed in eight per cent of premolar teeth under axial loading at a pH of 3.0, providing some support for the role of occlusal factors in the formation of NCCLs. However, given the low prevalence of NCCLs in their study, the authors stated that the simplistic model of occlusal stress and acid corrosion was invalid. Moreover, Litonjua *et al.*²³ have shown that artificial NCCLs can be produced in premolar teeth by toothbrush

abrasion with a slurry of toothpaste regardless of whether the teeth are loaded or not.

Clinical and anthropological studies may provide more fruitful approaches for understanding the aetiology of NCCLs. A critical review of abfraction has indicated that the force, frequency and method of toothbrushing are significant factors in the aetiology of NCCLs.² Some researchers have suggested that observed associations between occlusal wear due to attrition and presence of NCCLs provide support for the abfraction hypothesis,⁵ but these associations are weak in some instances.^{31,32} Even when such associations have been strong, occurrences of wedge-shaped NCCLs were found to be associated with both occlusal attrition and corrosion.⁷ Furthermore, the finding that NCCLs occur most frequently on buccal surfaces of teeth and rarely on lingual surfaces has been attributed to variation in salivary protection against corrosion at different intra-oral sites rather than occlusal stress.³³ An example of formation of an NCCL on a maxillary premolar with no opposing tooth has also been reported.³⁴ Furthermore, no NCCLs have been reported in the heavily worn dentitions of Australian Aborigines, except for interproximal grooving caused by processing kangaroo sinews.³⁵ Aaron³⁶ found that NCCLs did not occur in the dentitions of American Indians living in the 11th and 17th centuries, and he implied that NCCLs were probably a product of modern lifestyle factors, including overzealous toothbrushing and acidic diet, rather than tooth flexure.

Overall, the findings of the present investigation, along with those of other *in vitro*, clinical and anthropological studies, indicate that abrasion and corrosion are important factors involved in the formation of NCCLs. Although there are a few *in vitro* studies that support the abfraction hypothesis, clinical evidence linking occlusal stress to the formation of NCCLs is weak.² Longitudinal *in vivo* studies based on large samples are needed to elucidate the initial progression of NCCLs, and to test the validity of the abfraction hypothesis. Further *in vitro* studies that investigate the effect of toothbrushing in a corrosive environment could also improve our understanding of the aetiology of NCCLs. It is our view that occlusal adjustment should not be used as part of the management of NCCLs until the abfraction hypothesis is confirmed by stronger clinical evidence.

CONCLUSIONS

Based on microscopic assessment of a sample of extracted human teeth, the present study has confirmed that abrasion and corrosion are common associated aetiological factors in the formation of wedge-shaped NCCLs. Horizontal furrows of varying sizes were

identified in about half of the teeth examined, confirming the presence of both abrasion and corrosion. Further clinical studies are needed to clarify how NCCLs are initiated and to provide a sound basis for the clinical management of NCCLs. Until stronger clinical evidence is generated to support the abfraction hypothesis, occlusal adjustment for their management is not recommended.

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