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Micro-computerized tomography assessment of fluorescence aided caries excavation (FACE) technology: comparison with three other caries removal techniques

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ABSTRACT

Background: The aim of this study was to determine the caries removal effectiveness (CRE) and minimal invasiveness potential (MIP) of four dentine caries removal methods.
Methods: After carious molars were scanned using micro-computerized tomography (micro-CT), dentine caries were removed by fluorescence aided caries excavation (FACE) technology, laser induced fluorescence (LIF), chemomechanical excavation (CME), and conventional excavation (CE). Micro-CT was then repeated. CRE was determined based on the volume of residual caries/initial caries (RC/IC) and the mean mineral density (MD) at the cavity floor. MIP was determined by measuring the volume of the prepared cavity/initial cavity (PC/IC).
Results: Among the four groups, the LIF group had the smallest RC/IC (0.08), the highest mean MD at the cavity floor (1.32 g/cm^3) and the highest MIP (4.47). The CME group had the highest RC/IC (0.24), the lowest mean MD (1.01 g/cm^3) and the lowest MIP (2.23). The CE group exhibited a more acceptable CRE (RC/IC = 0.13, mean MD = 1.21 g/cm^3) but had a higher MIP (3.95). Both the CRE and MIP parameters of FACE technology were the second most acceptable (RC/IC = 0.12, mean MD = 1.13 g/cm^3, MIP = 3.20) and did not differ significantly from the most acceptable.
Conclusions: FACE is an effective caries removal technology for removing infected dentine without significantly increasing cavity size.

Keywords: Fluorescence aided caries excavation (FACE), dentine caries, caries excavation, Carisolv, DIAGNOdent, micro-computerized tomography.

Abbreviations and acronyms: ANOVA = analysis of variance; CE = conventional excavation; CME = chemomechanical excavation; CRE = caries removal efficacy; FACE = fluorescence aided caries excavation; LIF = laser induced fluorescence; LSD = least significant difference; MD = mineral density; micro-CT = micro-computerized tomography; MI = minimally invasive; MIP = minimal invasive potential; PC/IC = prepared cavity/initial cavity; RC/IC = residual caries to initial caries.

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INTRODUCTION

In recent years, the concept of minimally invasive (MI) dentistry has emerged. MI calls for the selective removal of heavily infected and irreversibly denatured dentine caused by carious lesions while preserving dentine that is demineralized but not infected.[1,2] Clinically, however, it is difficult to detect this boundary, which may lead to either under- or over-excavation.

Numerous caries excavation methods and techniques are available to dentists. Conventional excavation (CE) involves the use of a slow-speed tungsten carbide bur, and dentists determine the extent of the excavation by the hardness and colour of the dentine.[3] Clinicians commonly excavate until reaching the firm[4,5] dentine and rarely consider whether demineralized dentine could be preserved and might have the potential for remineralization.[6] Moreover, deciding on the depth of excavation based on the colour of the tissue and on hardness lacks a precise specification criterion.

Chemomechanical excavation (CME) of carious dentine has become an alternative to CE, particularly in paediatric dentistry[7] and for anxious or medically compromised patients.[8] This method disrupts the altered collagen fibres in carious dentine and allows a higher selectivity of removal. It also avoids the painful and excessive removal of healthy dentine.[7,9–12] A recent report[13] compared nine caries removal acquisition settings employed were 114 mA, 70 kV, 10 μm pixel size, and a rotation step of 0.7°. The resulting volume measurement was set as the baseline value.[36] A cut-off point corresponding to a MD value of 1.11 g/cm^3 HAp (as determined previously by correlating micro-CT grey values with hardness values of carious dentine[30]) was used as a cut-off point to segment each tooth into sound and carious volume in both the baseline and excavated caries section images.

Caries excavation

A single experienced dentist (XMZ) performed all of the caries removal procedures. Prior to the preparation of the cavity, all enamel overhangs from each lesion were removed in a minimally invasive procedure using a cylindrical diamond bur (Shofu Dental Equipment Co. Ltd., Japan) in a high-speed air turbine under water cooling until the underlying dentine lesion was exposed.

The 92 teeth that met the inclusion criteria were randomly divided into four groups according to the endpoint modality used (Table 1). Five teeth were excluded because the dentinal carious lesion was too small and seven other teeth were later excluded because of pulp exposure after caries excavation. The caries removal techniques tested are listed in Table 1.

In the CE group, the caries were removed using a tungsten carbide round bur (Shofu Dental Equipment Co. Ltd.) with a low-speed (approximately 1500 rpm) handpiece. This procedure was performed without water cooling.[13] Different sized burs were used depending on the size of the carious lesion. The caries removal endpoint was reached when a hard cavity floor was felt upon gentle pressure with a blunt dental explorer. The stained but hard dentine tissue was not removed in the procedure. The operating field was illuminated using a standard dental light unit.

The CME group was treated using a special Carisolv hand instrument (MediTeam, Goteborg, Sweden) according to the manufacturer's instructions. The cavity was covered with Carisolv gel (MediTeam) for 30 seconds. An excavator was then used to remove the carious tissue. This procedure was repeated until the caries removal endpoint based on the self-limiting capacity of the solution was reached.

Table 1. Caries excavation methods and respective caries removal endpoint used

Group	Caries excavation method	Caries removal endpoint	N
CE	Bur + blunt dental explorer	Hard cavity floor felt with a blunt explorer	18
CME	Carisolv + metal excavator	Self-limiting caries removal ability of the gel	20
LIF	Bur + DIAGNOdent	The mean value is lower than 15	20
FACE	Bur + red fluorescence marker	No red-orange fluorescence could be seen	22

In the LIF group, the bur was applied for caries removal and the DIAGNOdent was used to define the endpoint. The instrument was calibrated using a ceramic standard according to the manufacturer's instructions. The samples were dried briefly using compressed air. Tip A was applied and placed on the site to be measured. Measurements were repeated at several sites. Three consecutive measurements were performed and the average DIAGNOdent reading at the marked lesion area was used to determine whether to continue or stop excavating. The cut-off value corresponding to the measurement for healthy tissue was set at 15.[34]

In the FACE group, the cavity was excited using a 35 watt Xenon-discharge lamp and a blue band pass filter with peak transmission at 370 nm (Inspektor Research Systems Bv, Amsterdam, The Netherlands). Under these conditions, sound dental hard tissue fluoresces green and carious dental hard tissue fluoresces orange-red.[25] The operator inspected the cavity through a 530 nm yellow glass filter (OG530, Schott, Mainz, Germany) and removed orange-red fluorescing dentine, whereas green fluorescing areas were conserved. The room was darkened during the excavation procedure.[18]

Micro-CT analysis

Caries removal efficacy

The CRE was evaluated using two parameters: (1) the mean relative volume of residual caries to initial caries (RC/IC) and (2) the mean MD at the bottom of the cavity. The lower the RC/IC ratio, the more effective was the excavation of the caries. After recording the average MD, each caries excavated tooth was further classified as sound if the mean MD at the cavity floor was above the dentine caries cut-off point (1.11 g/cm3 HAp) or as carious if the average MD was lower than the cut-off point.[27]

Minimal invasiveness potential

The MIP of the different caries excavation techniques was evaluated by the relative cavity size (i.e. the PC/IC ratio).[13,18] A relative cavity size close to 1 indicates a perfect MIP, as the volume of the removed tissue (PC) corresponds exactly to the volume of the initial carious lesion (IC volume).[13] Figure 1 shows an example of the analysis performed based on the micro-CT data.

Statistical analysis

The CRE and MIP parameters measured for the four caries excavation techniques were compared by

Table 3. Comparison results of CRE among each group

Group	(Sound dentine%)			
(RC/IC value)	CE (77.8)	CME (50.0)	LIF (80.0)	FACE (91.0)
CE (0.131 ± 0.110)				
CME (0.239 ± 0.120)	*			*
LIF (0.079 ± 0.076)		**		
FACE (0.115 ± 0.071)		*		

*Compared with other groups, ANOVA analysis revealed a significant statistical difference ($p < 0.05$).
**Compared with other groups, ANOVA analysis revealed a significant statistical difference ($p < 0.01$).

Table 4. Comparison results of MIP among each group

Group (PC/IC value)	CE	CME	LIF	FACE
CE (3.946 ± 2.530)				
CME (2.230 ± 1.741)	*			
LIF (4.471 ± 3.230)		**		
FACE (3.197 ± 1.581)				

*Compared with other groups, ANOVA analysis revealed a significant statistical difference ($p < 0.05$).
**Compared with other groups, ANOVA analysis revealed a significant statistical difference ($p < 0.01$).

The CME group had the highest RC/IC value (0.239) among all methods tested, and the differences between it and the other groups were statistically significant (CE group, $p < 0.05$; FACE group, $p < 0.05$; LIF group, $p < 0.01$). The mean MD (1.01g/cm^3) at the cavity floor of this group was lower than the threshold MD (1.11g/cm^3), and this was true only for this method. The MIP value for the CME group (2.23) was the lowest among the methods tested, and it differed significantly from the value for the CE group ($p < 0.05$) and the LIF group ($p < 0.01$). These data indicate that the CME technique results in excessively conservative caries removal, with a significant amount of carious tissue remaining compared with the other three methods.

The LIF group had the lowest RC/IC value (0.079), which was significantly lower than that of the CME group ($p < 0.01$), but the differences in this value among the LIF, CE and FACE groups were not statistically significant. The MIP value of the LIF group was the highest among the methods tested (4.471), and it was significantly higher than that of the CME group (2.23, $p < 0.01$). These results indicate that the LIF method has a tendency to cause over-excavation.

The FACE group had the second lowest RC/IC value (0.015), and it was not significantly different from that of the lowest group (LIF, 0.079). The mean MD value of the FACE group came closest to 1.11g/cm^3 (1.13g/cm^3), and the caries-free ratio of the FACE group was the highest among the methods tested; only 2 of 22 teeth tested had an average MD lower than 1.11g/cm^3 at the cavity floor. These results show that the caries removal ability of this method is very consistent and effective. The MIP parameter of the FACE group (3.197) was higher than that of the CME group, but the difference was not statistically significant.

DISCUSSION

Our comparison of four caries removal techniques showed that FACE technology can leave a cleaner dentine floor than the CME method and preserve more sound dentine tissue than the LIF and CE methods.

The ideal caries excavation technique would be the one that selectively removes the irreversibly destroyed tissue but leaves the potentially remineralizable tissue at the cavity floor. Because a larger initial caries cavity means a larger cavity surface, comparison of RC volume only would not be valid for making comparisons among excavation methods. However, the relative volume of residual caries (i.e. RC/IC) should provide a fair comparison among techniques.

The CRE parameter can partly reflect the irreversibly destroyed tissue remaining after caries excavation, and the MIP parameter can partly reflect the tissue conservation condition. The CRE and MIP parameters are conflicting factors, but the selection of an effective caries excavation method should take both factors into consideration. This is hardly achievable clinically because even the currently available caries excavation techniques are not sufficiently specific to enable removal of only the irreversibly destroyed carious tissue. Indeed, some sound or at least potentially remineralizable tissue is frequently sacrificed to ensure that little bacteria-infected dentine remains.

In our study, both CRE and MIP were evaluated. The FACE technology had the best caries removal ability among the four methods tested. The orange-red fluorescence used as the caries removal marker is caused by porphyrins, which are by-products of the metabolism of oral microorganisms. Using porphyrins as a marker, the target is the bacterium. Our findings are consistent with those of Lennon *et al.*[20] who proposed FACE technology in 2002. The authors performed detailed studies and further developed this method in subsequent years. Various researchers have used histology to characterize the bacteria left after caries excavation using the FACE technology.[18] After application of the FACE method to excavate caries, teeth sections were evaluated for the presence of bacteria in the dentin tubules using light microscopy[19,35] or laser-scanning confocal microscopy.[18,20] Those studies confirmed that the FACE method removes more caries-affected tissue

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