Original Article

Evaluation and Comparison of Caries Excavation Efficacy of Three Different Burs: A Micro-computed Tomographic-assisted Study

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ABSTRACT

Aims and Objectives: The aim of this study was to evaluate the effectiveness of three different caries excavation methods using micro-computed tomography (micro-CT). **Materials and Methods:** Fifteen freshly extracted human molar teeth with occlusal dentinal caries were selected. The teeth were sectioned longitudinally into two halves and were randomly divided into three groups ($n = 10$) depending on the caries removal technique: Group 1: tungsten carbide (TC) bur, Group 2: cerabur (CB), and Group 3: Excavus (EX) tipEX). A preoperative micro-CT scan of all the samples was taken. The caries excavation procedures were carried out followed by postoperative micro-CT scan. The preoperative and postoperative scans of each tooth were analyzed for caries removal effectiveness (CRE), mineral density (MD), and minimal invasiveness potential (MIP) using Avizo 9.4 software (Thermo Fisher Scientific, Germany). Statistical analysis was conducted by applying three-way analysis of variance and independent sample t-test using the Statistical Package for the Social Sciences software, version 20.0 (IBM Corporation, USA). **Results:** Among the three groups, the TC group had the smallest RC/IC (residual caries/initial caries) ratio, highest mean MD at the cavity floor, and highest MIP. The EX group significantly had the highest RC/IC, lowest mean MD, and lowest MIP. Both the CRE and MIP parameters of CB group were acceptable (RC/IC = 0.08, mean MD = 1.09 g/cm^3, and MIP = 1.09). **Conclusion:** As compared with the three excavation methods, CBs can be considered as an alternative to TC burs because of its MIP and complete removal of infected carious dentin.

Keywords: *Cerabur, micro-computed tomography, mineral density, minimal invasive potential, sonoabrasion, tungsten carbide bur*

Introduction

Despite of many advances in the treatment of dental caries, prevalence is still increasing enormously. Recently, management of dental caries includes early detection of carious lesion, individual risk assessment, nonsurgical management, and dental tissue conservation. With the introduction of adhesive restoration, the need for retentive tooth preparation as applicable for amalgam restoration is no longer considered.[1-3]

Conventional method of tooth preparation for decayed tooth involves complete removal of the diseased tooth structure and designing a mechanical preparation for retaining the restorations. Earlier tooth preparations were based on G.V. Black's principle of "Extension for

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prevention." All the carious susceptible pits and fissure were included within the tooth preparation, and the margins were placed in sound enamel to prevent secondary caries. This concept has been recently challenged and is considered to be too invasive, compromising the pulpal health and the structural integrity of the tooth.[2,4] The distinction between the outer infected and inner affected dentins is required to preserve the dentin and allows the affected dentin to remineralize.[3,5] Various methods can achieve this selective removal of infected dentin. Sonoabrasion, chemomechanical caries removal, air abrasion, fluorescence-aided caries excavation (FACE), and newer burs (polymer burs and ceramic burs) have been suggested as techniques that result in selective removal of carious dentin.[6]

The cerabur (CBs; Komet-Brasseler, Lemgo, Germany) are all-ceramic round burs made of alumina-yttria-stabilized zirconia and are available in different diameter sizes. These burs are efficient in removal of soft infected dentin and at the same time provide tactile feedback to control the amount of dentin removal.[7]

Sonoabrasion allows for selective removal of enamel and dentin by using modified diamond abrasive tip mounted on a sonic device that oscillates in a concise length avoiding over preparation and causing no damage to the adjacent tooth during cavity. The sonoabrasion prepared cavity surfaces were also equally receptive to bonding procedures.[8] Excavus (EX) are set of five ultrasonic instruments that are diamond coated and available as EX1, EX2, EX3, EX-L, and EX-R tips, in which the EX1 tip, ball diamond tip (46 µm) with a diameter of 1.7 mm, is used for the preparation of the occlusal surface and cervical margins.[9]

Recently, micro-computed tomography (micro-CT) has been used for evaluating caries removal efficacy (CRE) and minimal invasive potential (MIP) of caries removal techniques. Neves *et al.*[10] proposed a detailed protocol using micro-CT to assess various caries removal technologies quantitatively.

The literature regarding the caries removal efficacy of sonoabrasion and CBs is sparse. This study aimed to compare two minimally invasive caries excavation methods to the conventional tungsten carbide (TC) excavation using micro-CT. The null hypothesis tested was that there would be no difference in CRE, mineral density (MD) of the cavity floor, and MIP between the three caries excavation methods tested.

Materials and Methods

This research was a single centered, *in vitro* observational study. The research was conducted in the Department of Conservative Dentistry and Endodontics, Saint Joseph Dental College, Andhra Pradesh, India from January 2016 to August 2017 after the approval from the institutional review committee.

Specimen preparation

G Power software, version 3.1.9 (Heinrich-Heine-Universität Düsseldorf, Germany) with values of standard deviation (SD) from the literature[10] was used for sample selection to get a power of 80% and limiting type 1 error to 0.05. Fifteen human molars without fillings, which had cavitated lesions into dentin, were selected from the bulk of teeth extracted for periodontal reasons and were stored in physiologic saline for not more than 2 weeks to minimize the changes in mechanical properties that occur on storage.[11] There was no wastage of the samples. Samples without dentine–caries involvement and the carious lesion less than 1 mm distance from the pulp chamber were excluded after radiographic evaluation [Figure 1].

Each tooth was bisected longitudinally through the center of the carious lesion using a circular rotating diamond disk (DFS-Diamon GmbH, Riedenburg, Germany). This resulted in a total of 30 samples that were randomly allocated to each group. The halves were then mounted securely in a wax block [Figure 2], and aluminum wire (1 mm in diameter and 10 mm in length) was mounted in the wax standing slightly away from the tooth for internal calibration.

Initial micro-computed tomography scan of the samples (pre-µCT)

A first micro-CT scan of the occlusal part of each tooth was performed using an Xradia XRM 500 desktop micro-CT (Carl Zeiss Microscopy GmbH, Göttingen, Germany) and the resulting three-dimensional (3D) volume was assigned to the "pre-µCT stack." The acquisition settings used were 89.7 µA, 100.23 kV, 9 W, and 14.6 µm pixel size using an LE4 filter and a rotation step of –90°. A flat-field reference was taken before the first scan, and the random-movement amplitude was set to 30 lines to reduce ring artifacts. To improve signal-to-noise ratio, 32-frame averaging was applied during the acquisition phase.

Calibration of mineral density of decayed, affected, and sound dentin

Three tooth slabs comprising sound dentin, carious dentine, and affected dentin were mounted in a wax block and scanned with the same parameters used for the first micro-CT scan of the sample. The linear accentuation coefficient values so obtained were converted into mineral

Figure 1: a. sectioning of the tooth samples using a diamond disc; b. sectioned samples

concentration and kept as standard to compare with those obtained before and after scanning of the samples.

(The MD values were depicted in the micro-CT software and the image/graph was not provided.)

Caries excavation procedures

The teeth were randomly assigned to one of three groups with 10 teeth each:

Group 1 (n = 10): Conventional TC bur (SS White, Lakewood, CA). Round bur no. 4 was used with a high-speed handpiece with water coolant. Carious dentin was excavated with circular movements starting from the periphery to the center of the lesion. Caries removal ended when hard dentin was detected using a dental explorer (GDC, Hoshiarpur, Punjab, India). Dentin was considered hard when, under firm pressure, the explorer was not able to penetrate the tissue [Figure 3].

Group 2 (n = 10): CB (K1SM.204.012, Komet, Rock Hill, SC). A no.12 CB was used with a low-speed contra-angle handpiece (Nakanishi, Tochigi, Japan) with an approximate speed of 1500 rpm, without water cooling. Tactile sensation provided by the instrument established the caries removal end point [Figure 3].

Group 3 (n = 10): Excavus EX1 (Acteon, Merignac, France). EX1 diamond tip was coupled with ultrasonic scaler unit (NEWTRON® P5 XS, Acteon, Merignac, France), with power setting at 12 and flow rate adjusted to 5 on the unit. Caries removal ended when hard dentin was detected using a dental explorer. Dentin was considered hard when, under firm pressure, the explorer was not able to penetrate the tissue [Figure 3].

Figure 2: Sectioned samples mounted on a wax block

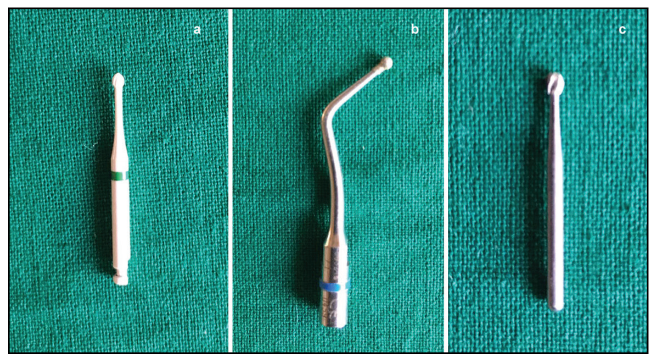

Figure 3: Armamentarium: Burs: a. cerabur; b. excavus tip; c. tungsten carbide bur

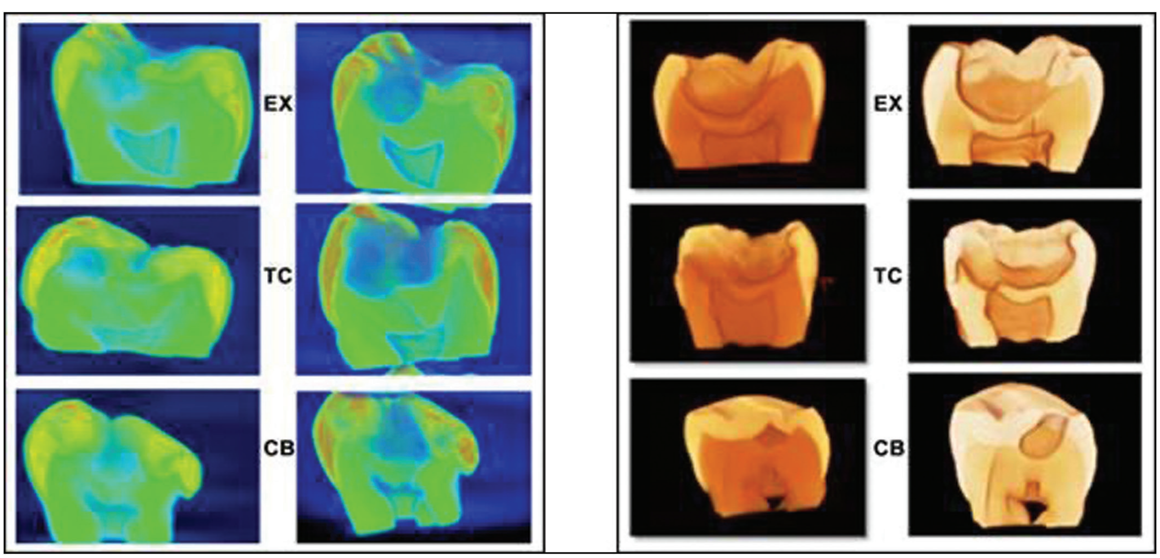

Figure 4: Micro-CT images of scanned teeth; preoperative (left), postoperative (right) of EX group, TC group, and CB group from top to bottom, respectively. Two modes of polychromatic images are displayed. TC = tungsten carbide, CB = cerabur, EX = exacavus

Post-excavation micro-computed tomography scanning

After excavation of caries in all groups, a second micro-CT scanning was performed using the same parameters as the initial scanning. The resulting images were assigned to post-µCT stack.

Reconstruction of the images

Image visualization and analysis were performed using Avizo 9.4 software. Each sample was given a code for easier interpretation. For instance, for TC bur group, in TC1a, "1" represents the first sample and "a" represents the pre-uCT stack. Similarly, in TC1b, "b" represents post-µCT stack. CB1a and CB1b were represented for CB group, and EX1a and EX1b for EX group.

Performance assessment of caries removal

(a) *Caries removal efficiency* was calculated by the time taken by the burs for complete excavation of caries. Time was calculated from starting point till the complete excavation of caries.

(b) *CRE* was evaluated using two parameters measured after caries excavation as suggested by Zhang *et al.*[12] The parameters are as follows:

i. The mean relative volume of residual caries (RC).

ii. The mean MD at the bottom of the cavity.

The mean relative RC volume or RC/IC ratio was obtained as the ratio of the volume of carious tissue segmented in the excavated caries stack (RC) over the volume of carious tissue segmented in the baseline stack (initial caries or IC). The values of this parameter vary from 0 to 1, and high values represent less-effective caries excavation. The MD at the cavity floor was calculated from a selected volume of interest (VOI) with a thickness of 70 µm at the deepest dentine part of the cavity in the excavated caries volumes. The excavated caries volumes were then assigned as sound or carious based on the MD determined earlier.

(c) *MIP*.

The minimal invasiveness potential (MIP) of the different caries excavation techniques was evaluated as described by Neves *et al.*[10] The relative cavity size was obtained by the ratio of prepared cavity to the initial cavity. From each tooth, the excavated caries stack was subtracted from the baseline volume, by which the volume of the prepared cavity was obtained. The relative cavity size value of 1 indicated a better MIP of that group.

Statistical Analysis

Minimum and maximum values, mean, and SD were obtained for the described parameter using a one-way analysis of variance (ANOVA) test. Independent sample *t*-test was performed to evaluate significant statistical difference among the groups. The statistical analysis was performed using the Statistical Package for the Social Sciences software, version 20.0. A value of $P < 0.5$ was considered statistically significant.

Result

From the micro-CT result [Table 1], no significant difference was found between the IC mean values of the three groups indicating almost similar preoperative tooth carious lesion size. Figure 4 represents the polychromatic micro-CT image of the pre-µCT stack and post-µCT stack of three experimental groups.

i. *Time taken for excavation (caries removal efficiency)*. When mean excavation times were considered, the TC group (mean = 61.6 s) was the quickest among the three and slowest being sonoabrasion (mean 205 s). The CB group was of the intermediate with the mean value of 158 s. The results of one-way ANOVA test showed significant differences between the groups at $P < 0.05$. Independent sample *t*-test showed significant differences among the groups. A box and whisker plot shows TC bur being quickest among the three groups [Figure 5].

ii. *CRE.*

From Table 2, the EX group had the highest RC/IC value with the TC group being the least. A three-way ANOVA test revealed a significant difference between the groups ($P < 0.05$). When independent *t*-test was performed among the groups to compare RC/IC, there was a significant difference between TC-EX group and EX-CB group (0.000 and 0.003, respectively). There was no significant difference between TC and CB group indicating both are efficient in removing carious dentin. The Ex group showed higher values of RC ($2.61 \pm 0.53\,mm^3$), which were statistically significant as compared with the other two groups.

The MD values of sound, caries dentin, affected dentin, and three groups were plotted on the graph [Figure 6]. The sound dentin had the mean MD value of $1.26\,g/cm^3$, whereas the carious infected dentin and affected dentin had mean MD value of $0.33\,g/cm^3$ and $0.78\,g/cm^3$, respectively. These values were used to compare the effectiveness of the experimental groups. It is evident from Figure 1 that the TC ($1.18\,g/cm^3$) group had MD value approaching to that

Table 1: The micro-CT results

Group	Mean RC (mm^3)	Mean IC (mm^3)	Mean PC (mm^3)	Mean mineral density (g/cm^3)
TC	0.877 ± 0.22	21.512 ± 5.88	29.13 ± 5.47	1.18
CB	1.226 ± 0.34	17.232 ± 4.93	19.875 ± 4.79	1.09
EX	2.61 ± 0.53	18.218 ± 4.96	21.525 ± 5.86	0.81

TC = tungsten carbide, CB = cerabur, EX = exacavus of sound dentin (1.26 g/cm[3]). The CB group had a lower MD value as compared to the TC group, and there was a significant difference between the groups. The mean MD value of EX group was 0.81 g/cm[3], which was nearer to the mean MD value of affected dentin (0.78 g/cm[3]). This indicated that EX group excavated only carious infected dentin leaving behind the affected dentin conserving tooth structure. The independent *t*-test revealed a significant difference among the experimental groups.

iii. *MIP*

The MIP obtained by PC/IC ratio is more for the TC group (1.18) resulting in over-excavation [Table 3]. The EX group had MIP value of 0.81, which is less than 1 indicating that it produced very conservative cavity preparation. The mean MIP value of CB group is 1.09, which is very close to 1 indicating a consistent and effective cavity preparation. The mean MIP values were significant among the groups when a three-way ANOVA test was used. Independent *t*-test was used to evaluate statistical significance among the groups at $P = 0.05$. There was no statistical difference between the CB and EX groups indicating that both were almost identical in terms of caries excavation. Both excavation techniques resulted in conservative cavity preparation. In contrast, there was a significant difference between TC-EX ($P = 0.047$) and TC-CB ($P = 0.020$) groups.

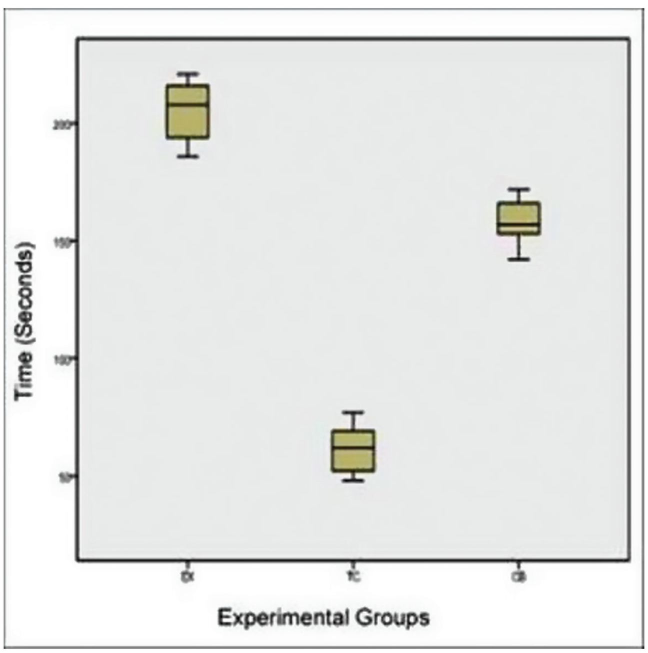

Figure 5: Box and whisker plot demonstrating the time taken by the experimental group for caries excavation. The box for each group provides the median, upper, and lower observation values. TC = tungsten carbide, CB = cerabur, EX = exacavus

Discussion

The modern concept of minimally invasive dentistry requires caries excavation techniques to preserve as much as possible potentially mineralizable dentin, thereby enhancing the structural integrity of the tooth. This is difficult to achieve clinically as all the excavation techniques have inadvertently sacrificed sound dentin in varying amount.[4] The purpose of this *in vitro* study was to compare the caries removal efficiency of TC burs with the selective caries removal techniques of "sonoabrasion" and "ceramic burs."

Micro-CT was selected in this study as it provides a 3D image without the need for sample preparation. This also offers the advantage in providing high-resolution images that can be used for 3D reconstructing to evaluate the surface area, MD changes, and surface topography of the sample. All these precise calculations can be carried out with minimal involvement of time.

Caries removal efficiency

The TC bur was the quickest among the three methods, and this was in accordance with Banerjee *et al.*[13] The mean excavation time for the bur in their study was 57.1 s, which is close to resulting of this study.

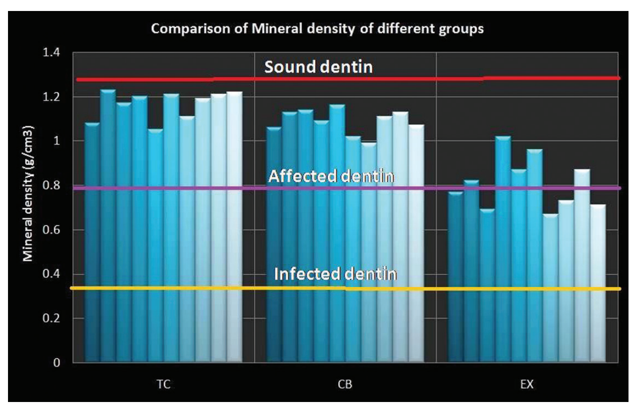

Figure 6: Bar graphs depicting the mineral density values of carious dentin, affected dentin, sound dentin, and three experimental groups. Note the mineral density values of TC group approach the sound dentin mineral density value

Table 2: Mean, SD, and maximum and minimum values of RC/IC and MIP in the three groups by ANOVA one-way test

Group		Min–max	Mean	SD	*P* value		Min–max	Mean	SD	*P* value
TC	RC/IC	0.02–0.14	0.05	0.04	0.000*	MIP	1.05–1.30	1.18	0.08	0.017*
CB		0.04–0.15	0.08	0.04			0.99–1.16	1.09	0.05	
EX		0.08–0.27	0.15	0.05			0.67–1.02	0.81	0.12	

TC = tungsten carbide, CB = cerabur, EX = exacavus, RC/IC = residual caries/initial caries, MIP = minimal invasive potential

*$P < 0.05$ indicates significant at 5% level

Table 3: Comparing results of RC/IC ratio and MIP among each group

	Group	TC	CB	EX		Group	TC	CB	EX
	TC (0.05 ± 0.04)			0.000*		TC (1.2 ± 0.16)			0.047*
RC/IC	CB (0.08 ± 0.04)	0.073*			MIP	CB (1.42 ± 0.29)	0.020*		
	EX (0.15 ± 0.05)		0.003*			EX (1.17 ± 0.09)		0.678*	

TC = tungsten carbide, CB = cerabur, EX = exacavus, RC/IC = residual caries/initial caries, MIP = minimal invasive potential
*$P < 0.05$ indicates significant at 5% level

Residual caries/initial caries ratio

The RC/IC ratio indicates the probability of residual non-reminerizable caries at the cavity floor. The conventional TC bur resulted in low RC/IC ratio indicating near complete removal of caries dentin with cavity floor placed in sound dentin. Although such sound dentin cavity floor is required for better bonding[5] and to ensure bacteria-free, it unnecessarily removes remineralizable affected dentin. The low RC/IC ratio of TC group was also in agreement with that of Zhang *et al.*[12] and Neves *et al.*[10] TC burs are designed with negative rake angle and are used at high speed. This results in less tactile feedback, faster, and nonconservative method of dentin caries removal.[5]

The RC/IC ratio of CBs was also low and similar to the TC group. The nonsignificant difference between the TC and CB group reveals that the CB group is not selective in caries removal as proposed by the manufacturer. Dammaschke *et al.*[14] using histological staining revealed that CBs were as effective as TC burs in caries excavation. In their study, CB and TC burs had 10.2% and 7.9% of the sample with remaining caries and there was no significant difference.

In contrast to this study, Neves *et al.*[15] showed more RC at the cavity floor with CB and pointed out that a learning curve is required with respect to force applied during caries removal, which may improve the CRE of CBs.

The RC/IC ratio of EX group (sonoabrasion) was found to behigher indicating a substantial amount of RC at the cavity floor. Neves *et al.* compared nine excavation methods and found that the cavity floor was free of RC when sonoabrasion was used. The difference between this study and Neves *et al.*[15] may be attributed to TC tip of sonoabrasion (Cariex) in their study. The EX tip used in this study contained diamond abrasives, which would have resulted in the compacting effect of carious dentin giving a false indication of the clinical end point of caries excavation having been reached.[16]

Minimal invasive potential

The MIP value of CB was 1.09 indicating a conservative cavity preparation. The TC group resulted in invasive cavity preparation, whereas the EX group had a value of 0.81. Zhang *et al.*[12] reported that CRE and MIP are conflicting factors that have to be taken into consideration for selection of effective caries excavation techniques. MIP value should be 1; the value of MIP <1 indicates the insufficient cavity preparation with RC remaining in the cavity floor. MIP should not be achieved at the cost of RC as caries that were excluded may result in insufficient bond strength to tooth structure.

Mineral density

This is the first study where an MD of carious, and affected and sound dentin was analyzed. This study was performed to compare the carious excavation potential of all three systems. Neves *et al.*[10] proposed a detailed protocol for using micro-CT. The density value of 1.11 g/cm^3 was defined as the threshold density between carious and sound dentine. This cutoff point was used to evaluate the excavation techniques. The MD values of sound enamel, dentin, and carious dentin vary according to different studies. Clementino-Luedemann *et al.*[17] using micro-CT obtained mineral concentration value of 2.74–2.52 g/cm^3 and 1.36–1.51 g/cm^3 for sound enamel and dentin, respectively. The mineral concentration values change according to the location of dentin. Neves *et al.*[10] obtained MD values of 2.89, 1.74, and 0.27 g/cm^3 for enamel, dentin, and caries, respectively. The region of interest (ROI) in this study for dentin MD was analyzed at the center of the dentin slab. This would have resulted in the difference between this study and others.

The invasive potential of the TC group also resulted in cavity floor with sound dentin with an MD value of 1.18 g/cm^3, which is close to sound dentin. The CB also resulted in a cavity floor with sound dentin. In a study by Neves *et al.*,[15] CB tended to leave more caries at the cavity floor than TC and sonoabrasion. In another study, the authors found better bond strength of CB group to dentin.[18] These contradictory findings should be considered carefully. The lowest value of MD at the bottom of the cavity (0.81 g/cm^3) was recorded for the EX group, which is very close to the density of the affected dentin slab, indicating that EX method of excavation was accurate in excavating only the infected dentin.

Limitations

Morphological analysis along with mineral composition of dentin layer after caries excavation would have provided clear picture of substrate properties. Future studies comparing sonoabrasion and CBs with other minimally invasive caries excavation techniques may provide better insight for selecting the methods that aim at dental tissue conservation.

Conclusion

The TC bur remains the method of choice for caries excavation as it provides an ideal substrate for bonding.

CB with its better mechanical properties can be considered as an alternative for TC, which is efficient in caries removal and is not as invasive as TC bur. EX group though presented with better MIP value retained significant RC resulting in under preparation.

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Nil.

Conflicts of interest

There are no conflicts of interest.

Authors contributions

Vinay Vusurumarthi: Conception and design, acquisition, analysis, interpretation of data for the work. Drafting the work and revising it critically. Final approval of the version to be published, and accountable for all aspects of the work in ensuring that questions related to the accuracy. Srinidhi V. Ballullaya: Conception, designing and drafting of the work, final approval of the version to be published. Shankarappa Pushpa: Conception, interpretation of data for the work, revising manuscript critically, final approval of the version to be published. Venkata Ramya K. Veluvarti: Design, acquisition, analysis, interpretation of data, and revision for the work, final approval of the version to be published. Pramod R. Loka: Design of the work, drafting the work, approval of the final version to be published. Pavan K. Galla: Conception and design of the work, the acquisition, analysis, revising it critically for important intellectual content, final approval of the version to be published.

Ethical policy and institutional review board statement

Ethical committee name: Institutional Ethical Committee number: CEC/4/2015-16.

Patient declaration of consent

Not applicable.

Data availability

Data is not available in any electronic format in any domain. If requested by anyone, will be provided.

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