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Effectiveness of Different Mechanical Methods on Dentin Caries Removal: Micro-CT and Digital Image Evaluation

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Clinical Relevance

Selective caries removal is an important goal in dentistry, and caries-affected dentin should be preserved. Polymer burs could represent an important minimally invasive tool to preserve remineralizable dentin substrate during caries excavation.

SUMMARY

Purpose: To determine the caries removal effectiveness (CRE) and minimal invasive potential (MIP) of caries excavation methods using digital imaging and microtomography analyses.

Methods: Twelve human molars with occlusal caries lesions in dentin were randomly divided into three groups (carbide bur, exacavator, and polymer bur). They were sectioned mesiodistally, and standardized digital and computed microtomography x-ray (micro-CT) images were taken from each section before and after caries excavation. On each image, initial carious dentin (IC), prepared cavity (PC), and residual caries (RC) were defined according to visual criteria using ImageJ software. CRE was determined based on the RC/IC ratio, whereas MIP was determined by the PC/IC ratio. Data were analyzed using one-way analysis of variance and Student *t*-test or with Kruskal-Wallis and Student-Newman-Keuls test. The level of significance was set at 0.05.

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Results: For both digital image and micro-CT analysis, the carbide bur showed higher CRE values than the excavator (p=0.0063 and p=0.0263, respectively) and the polymer bur (p=0.0028 and p=0.0005, respectively). The latter two presented similar results (p>0.05). Regarding MIP, for the digital image analysis, the polymer bur was different from the carbide bur (p=0.0030) but was not different from that of the excavator (p=0.1240). For micro-CT analysis, the MIP values of all the groups were significantly different, and the polymer bur was the most conservative method (p<0.05).

Conclusions: The carbide bur was the most effective method for caries removal but was not completely conservative. The polymer bur and excavator presented low invasive potential but were not able to remove all of the carious dentin.

INTRODUCTION

In light of the trend toward minimally invasive dentistry, caries excavation has become more conservative.[1] Theoretically, only the superficial layer (ie, infected dentin that is strongly infected with viable microorganisms and presents irreversible denaturation and disorganization of the collagen fibers),[1] should be removed. Clinically, this is a difficult task to achieve. Traditionally, carious dentin is removed mechanically with excavator and/or slow-speed round diamond, tungsten carbide, or carbon-steel burs.[2,3] However, these techniques are indiscriminant and nonselective in removing carious tissues. Often during excavation, clinicians tend to include all soft, discolored, and stained tissue to ensure complete elimination of the infected layer.[4,5] In such cases, tactile and optical judgment is used to evaluate the consistency and color of the dental tissue. These criteria were shown to be adequate to ensure the removal of most of the infected dentin,[5] but they are still clinical and subjective parameters, dependent on the operators' experience.[1] Thus, their use frequently results in unnecessary removal of sound dentin or tissue with reduced mineral content, such as caries-affected dentin,[3,4] that is still a remineralizable organic matrix of the lesion and therefore must be preserved.[1,4]

Alternative caries removal methods such as polymer burs, air abrasion, and chemomechanical methods have been proposed to allow a less invasive/less destructive dentin caries excavation and to conserve tooth substance. A gentler, more comfortable and conservative caries excavation will provide a minimal thermal change, less vibration and pain, and removal of the infected dentin only.[6-10]

Polymer burs were first described by Boston in 2003.[10] They are made of a polyamide–imide polymer and present slightly lower mechanical properties than sound dentin. The blade design was developed to remove dentin by locally depressing the carious tissue and pushing it forward along the surface until it ruptures and is carried out of the cavity.[10] According to the manufacturer, this material is harder than infected dentin but softer than normal and sclerotic dentin, thus allowing a very selective caries removal. However, the efficacy of these new burs on selectively and efficiently removing natural carious dentin in permanent teeth is not well established.

X-ray computed microtomography (micro-CT) is a microscopic version of computed tomography that uses an x-ray–focused beam. It constitutes a nondestructive imaging method in which individual projections (radiographs) can be re-created in any plane[11] and images may be assessed qualitatively and quantitatively. More recently, studies have been developed regarding using this technique in the evaluation of enamel lesion caries, detection of proximal carious lesions, caries-excavation techniques, and restorative treatments. This seems to be promising in cariology.[2,6,11-14] Despite its many advantages, micro-CT is not yet a reliable method for caries detection, and for this reason, more studies are necessary to evaluate and define its feasibility as a diagnostic method.

The digital image analysis also represents a nondestructive imaging method and is a powerful tool for the study of a wide range of materials and parameters. Therefore, the use of digital imaging and subsequent image analysis is expected to successfully assess the performance of different types of burs in the carious excavation process.[15]

This study aimed to assess the caries removal effectiveness (CRE) and the minimal invasiveness potential (MIP) of mechanical excavation methods on dentin caries using microtomography and digital imaging analyses. The null hypotheses tested were (1) all mechanical methods will be equally effective at removing dentin caries and (2) none of the methods will remove sound dentin.

METHODS AND MATERIALS

Sample Preparation

Twelve extracted human molars with dentin caries on their occlusal surfaces were collected. Immedi-

ately after extraction, the teeth were properly cleaned and stored in a 0.1% (w/v) thymol solution for a period of no longer than three months. The roots of all the teeth were embedded in acrylic resin in a mold with dimensions of $2 \times 2 \times 2$ cm. They were then sectioned longitudinally in half through the center of the carious lesion using a low-speed diamond saw[15] (IsoMet Low Speed Saw, Buehler, Lake Bluff, IL, USA) under running water. A visual inspection was performed to determine the limits of the caries lesion. All of the teeth presented occlusal dentin caries. Teeth were randomly allocated to three experimental groups of four samples each.

Each section of tooth was digitally photographed[15] (Sony α300, Sony Corp, Tokyo, Japan), and micro-CTs (Skyscan 1174 high-resolution desktop micro-CT scanner, Skyscan, Kontich, Belgium) were taken before caries excavation. All images were assigned as "pre-rank." Tooth halves were reassembled with cyanoacrylate glue (Loctite Superbond, Henkel, São Paulo, Brazil) applied on the external surface of the crown, matching both halves together to remove the carious lesion.[15] Only one operator performed the caries removal. Training sessions were carried out by a principal investigator to calibrate the operator to remove caries using the three methods. The following describes the groups.

Group 1 (n=4)—Conventional round carbide bur. Burs 4, 6, and 8 (Dentsply Maillefer, Ballaigues, Switzerland) were used in a slow-speed hand piece without water cooling. Carious dentin was excavated with circular movements starting from the periphery to the center of the lesion.[16] Caries removal ended when hard dentin was detected using a nonflexible probe (SS White Duflex, Rio de Janeiro, Brazil). Dentin was considered hard when, under a firm pressure, the probe was not able to penetrate into the tissue.[4] For each tooth, a new carbide bur was used.[15]

Group 2 (n=4)—Excavator. Carious dentin was removed using excavators 14 and 19 (SS White Duflex). During excavation, the dentin hardness was checked and the carious dentin removal was completed when hard tissue was detected with the probe (SS White Duflex), as described for group 1. For each tooth, a new excavator was used.

Group 3 (n=4)—Polymer bur. SmartBurs II 4, 6, and 8 (SS White, Lakewood, NJ, USA) were used with a slow-speed handpiece without water cooling. Carious dentin was removed with circular movements starting from the center of the lesion to the periphery as recommended by the manufacturer. Excavation ended when the instrument became macroscopically abraded and blunted and was no longer able to remove tissue.[9,15] A probe was also used to check the hardness of the remaining tissue. For each tooth, new burs were used.[11]

During the time between procedures, the samples were stored in a physiological solution with a relative humidity of H=100%. After finishing the caries excavation, tooth halves were separated. Digital images and micro-CTs were taken and assigned as "post-rank."

Digital Images

The specimens were placed over a 45° tilted base inside a viewing cabinet (VeriVide CAC60, Verivide Ltd, UK) under constant CIE D65 illumination. For each sample, both before and after the caries removal procedure, 20 consecutive digital images were taken using a digital single lens reflex commercial camera (α300, Sony Corp) operating in manual mode with fixed parameters. The camera was calibrated using a spectroradiometer (PR704, Photo Research Inc, Chatsworth, CA, USA) and a Color Checker (Gretag Macbeth, New Windsor, NY, USA). The geometry of measuring/illumination used for the camera calibration was 0°/diffuse, and the CIE 1931 2° standard observer (CIE Bureau, 2004) was used to calculate the color.[15]

X-ray Micro-CT

The surfaces of all the halves were scanned before and after caries removal at 50 kV, 800 μA, and 14.1 μm pixel size using a 0.5-mm Al filter. This eliminates low-energy x-rays in a Skyscan 1174 high-resolution desktop micro-CT scanner (Skyscan, Kontich, Belgium). The rotation step was set to 0.70°, resulting in 264 two-dimensional projections over a 180° rotation of the specimen. A flat-field reference was taken before the start of time section scanner to improve the acquisition settings. The reconstruction program NRecon (NRecon, SkyScan) reads angular shadow 16-bit projection images saved by the control program and reconstructs virtual slices (cross sections). Before the reconstruction, beam-hardening correction was performed at 20%, with the same scanning parameters aiming at input of optimal contrast limits, based on prior scanning and reconstruction of the tooth.

After reconstruction, Dataviewer software (SkyScan, Kontich, Belgium) was used to select the two-dimensional image most similar to the respective digital image sample, and it was saved as a single image for further analyses and comparisons.

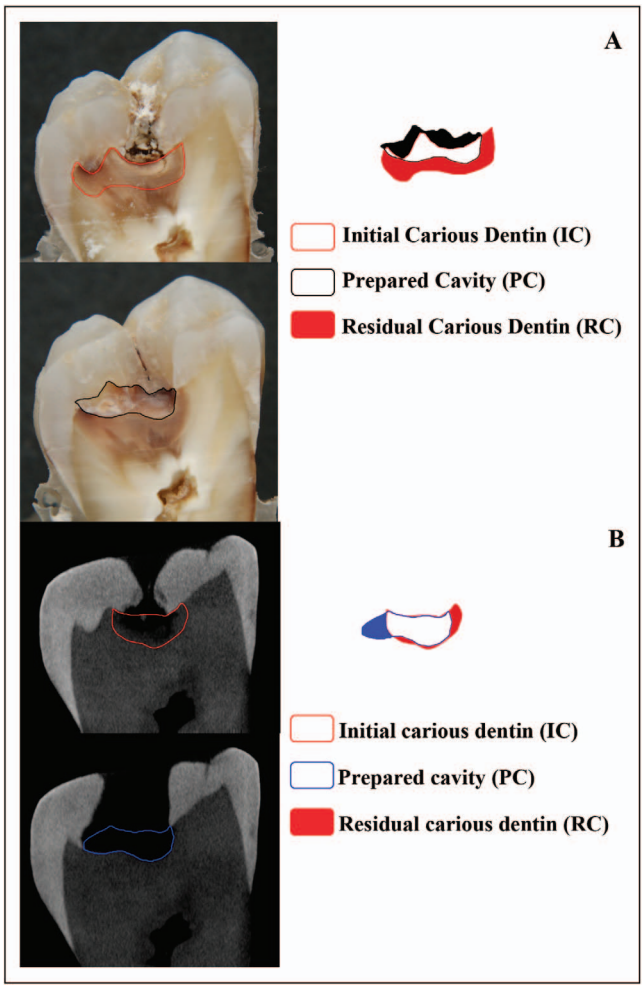

Figure 1. *Schematic representation of digital image and micro-CT analysis.*

Image Analysis

All of the steps, including the image processing, image analysis, and area measurement, were performed using the software ImageJ (National Institutes of Health, Bethesda, MD, USA). For each specimen, two areas of interest (initial carious dentin [IC] from pre-rank and prepared cavity [PC] from post-rank) were measured (Figure 1). The residual carious dentin (RC) and removed sound dentin (RS) areas were also determined (Figure 1). Digital image scaling and calibration were used to calculate the area values. The final result for each sample was the average over 20 images.[15]

Performance Assessment of Caries Removal Procedures

After obtaining all area measurements, performance assessment of the three different caries removal procedures was carried out by evaluating the CRE and the MIP indexes, supported in Neves and others.[6]

1. CRE: The effectiveness of caries removal of the three excavation methods was evaluated by means of the RC/IC ratio. The values of this parameter vary from 0 to 1, and high values represent less effective caries excavation.
2. MIP: The invasiveness of sound dentin of the three excavation methods was evaluated by means of the PC/IC ratio. The values of this parameter vary from 0 to 1. The higher the MIP value, the more invasive is the method.

Statistical Analysis

Means and standard deviations were determined for the described parameters (CRE and MIP). After testing for normality (Shapiro-Wilk test), those that did not pass were given nonparametric tests (Kruskall-Wallis and Student-Newman-Keuls). Those that did pass were given one-way analysis of variance and Student *t*-test. A value of $p<0.05$ was considered to be statistically significant.

RESULTS

Results of CRE and MIP are shown in Table 1 and Figure 2.

There were statistical differences for CRE between the groups ($p=0.0034$) according to digital imaging analysis. The carbide bur was statistically more effective in removing caries (0.00 ± 0.01) than was the excavator ($p=0.0063$) and the polymer bur ($p=0.0028$). The excavator and the polymer bur showed similar effectiveness ($p=0.8957$). Statistical differences were found for MIP between the groups ($p=0.0122$). The carbide bur and the excavator did not show significant differences regarding their MIP to remove sound dentin ($p=0.2092$). The MIP values of the polymer bur (0.57 ± 0.27) were statistically different from those of the carbide bur ($p=0.0030$) but were not statistically different from the excavator ($p=0.1240$).

There was a statistical difference for CRE between the groups ($p=0.0020$) according to micro-CT image analysis. The carbide bur presented greater effectiveness (0.00 ± 0.00) than did the excavator ($p=0.0263$) and the polymer bur ($p=0.0005$). There was a statistically significant difference for MIP between the groups investigated ($p=0.0001$). The carbide bur was the most invasive method (1.12 ± 0.14), and its MIP values were statistically different from those of the excavator ($p=0.0030$) and the

Table 1: *Mean ± SD of Caries Removal Effectiveness (CRE) and Minimal Invasive Potential (MIP) According to Different Carious Removal Methods Using Digital Image and Micro-CT*[a]

Caries Removal Method	CRE (Mean ± SD)	MIP (Mean ± SD)
Digital image		
Carbide bur	0.00 ± 0.01 A	1.09 ± 0.11 a
Excavator	0.33 ± 0.37 B	0.84 ± 0.44 a,b
Polymer bur	0.41 ± 0.32 B	0.57 ± 0.27 b
Micro-CT		
Carbide bur	0.00 ± 0.00 α	1.12 ± 0.14 γ
Excavator	0.30 ± 0.29 β	0.69 ± 0.27 δ
Polymer bur	0.73 ± 0.16 β	0.26 ± 0.14 ε

[a] *In the same column, different letters or symbols indicate significant difference (p<0.05).*

polymer bur ($p<0.001$). The polymer bur presented the lowest MIP values which were significantly different from the excavator ($p=0.0031$).

DISCUSSION

On both the digital image and the micro-CT analysis, the excavator and the polymer bur showed similar CRE, which was lower than that of the carbide bur (Table 1; Figure 2). Thus, the first hypothesis was rejected. A CRE ratio higher than 0 means that the excavation method could not completely remove the caries. In other words, the excavation methods were not sufficiently effective. The similarities in CRE of the excavator and the polymer bur could be attributed to the carious dentin's characteristics. Carious dentin, especially caries-infected dentin, presents a low cohesive strength,[2] a low degree of mineralization, and a high collagen matrix disorganization,[9,17] which are more easily removed. In the current study, it was speculated that carious dentin left by the polymer bur could be the effect of its self-limiting capacity, as previously reported.[15] In fact, it is possible that the polymer bur is not really able to remove caries-affected dentin because of its self-limiting effect. As a consequence, the low effectiveness of this method compared with the carbide bur represents an advantage toward dentin preservation and conservative caries removal. Toledano and others[15] demonstrated that the polymer bur was the excavation method that most preserved the carious-affected dentin. However, some authors consider remaining

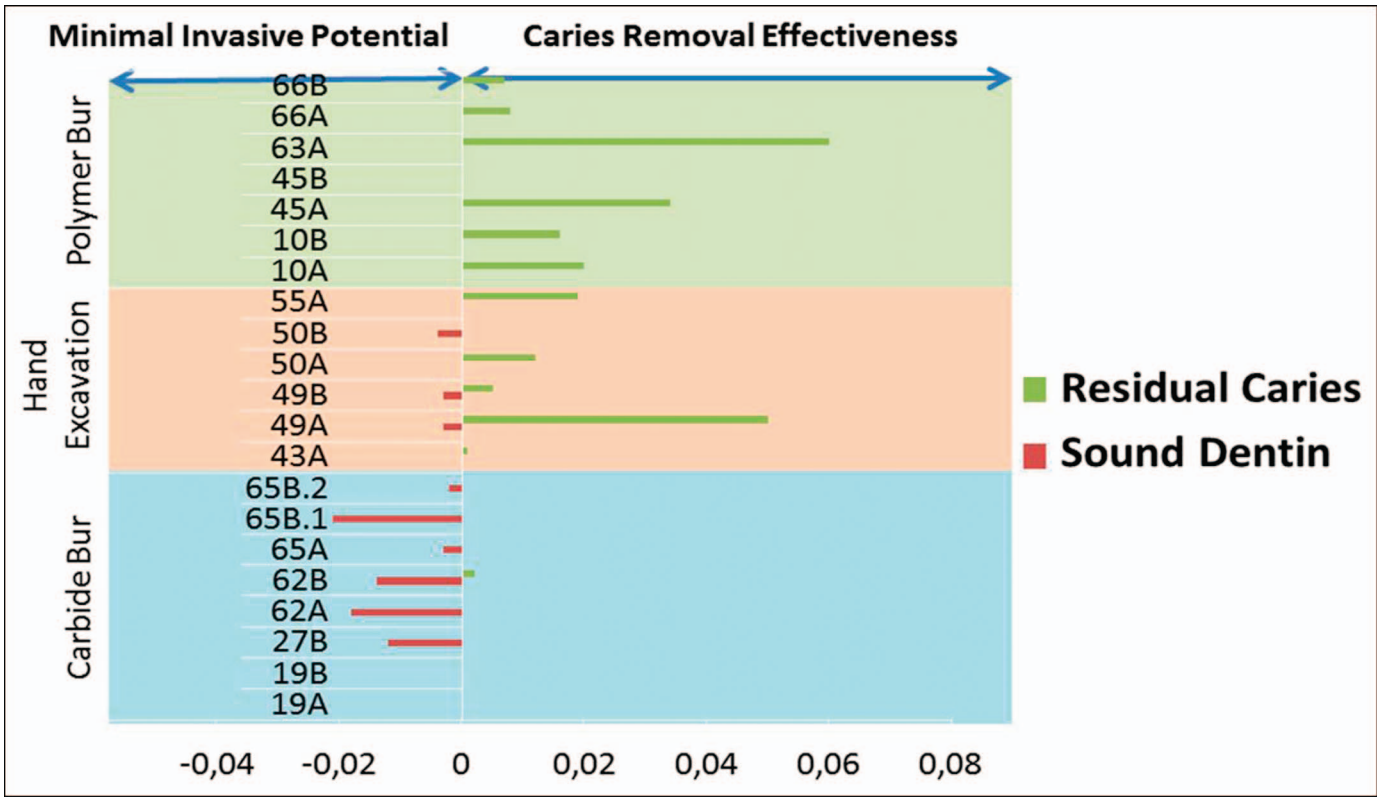

Figure 2. *Schematic representation of caries removal effectiveness (CRE) and minimal invasive potential (MIP) according to different carious removal methods using digital photography and micro-CT for each specimen.*

caries-affected dentin as unremoved and under-excavated caries.[16]

The hardness of the polymer bur (50 KHN) is higher than the hardness attributed to carious dentin (0 to 30 KHN) but lower than that of sound dentin (70 to 90 KHN). The bur could be damaged when touching sound dentin resulting in the inability to the remove all carious tissue.[9] On the other hand, some studies report that caries-affected dentin hardness is about 30.7 to 33.9 KHN.[18] Considering these hardness values, the polymer bur is not able to preserve caries-affected dentin and is not precise enough to distinguish the slight differences between the remineralizable dentin and that with minimal collagen degradation.[19]

In addition, the polymer bur presented a lower MIP than the carbide bur and this value was lower than 0 (Table 1; Figure 2). When the MIP ratio is lower than 1, it means that the prepared cavity was smaller than the initial carious lesion, and residual carious dentin could have been left behind. This could be more evidence that the polymer bur does not excavate into sound dentin tissue and was not able to totally remove the caries. In fact, these results are in agreement with other studies[10,15,16] that showed that the polymer bur excavation led to one of the largest coincidences between the caries removed and the caries lesion limits; they also exhibited the biggest underprepared area of all methods evaluated. Residual carious dentin might be left at the cavity walls due to the presence of a compact and thick smear layer, produced during the use of the polymer bur.[15] This is the so-called compacting effect on carious dentin, and it is likely that the carbide bur produces the same effect.[3,19] Such an effect could hinder and compromise the action of the polymer bur despite its self-limiting properties. The authors speculate that this similar effect could also happen during tooth storage, which is different from the clinical situation. Vital teeth contain dentin fluid that exudes from the pulp tissue to the dentin surfaces that have been prepared to keep it moist.

For digital and micro-CT analysis, the excavator presented MIP values that were somewhere between both extremes of the burs (Table 1; Figure 2). Specifically, in the digital image analysis, there was no significant difference between these values and those of the carbide and polymer burs (Table 1). According to the current findings, it seems that the excavator is not as invasive as the carbide bur, but it is more able to remove carious dentin beneath the compact smear layer than the polymer bur. Since dentin hardness may vary between teeth and even locally in the same tooth, its assessment usually varies between operators, and erroneous removal of dentin (over- or underpreparation) may occur.[11] The excavator is considered a suitable excavation method combining good excavation time and effective caries removal.[16] But, optimal effectiveness depends on clinical judgment and the operator's experience.[3]

On the other hand, the carbide bur presented the lowest CRE (0.00 for both digital and micro-CT images; Table 1; Figure 2). These low values mean that the carbide bur left almost no residual carious dentin, which is effective when removing caries. Prior studies also reported that the steel and carbide burs showed similar demineralized dentin removal effectiveness as the excavator.[16]

The caries removal endpoint has still not been well established and continues to be subjective. Determining the endpoint with a dental probe and dentin hardness is no longer the most reliable method as it does not take caries-affected dentin into account. Indeed, overexcavation can occur when probes are used in conjunction with traditional caries removal methods (ie, carbide burs).[2,3] An MIP ratio higher than 1 means that the prepared cavity was greater than the initial carious lesion (Table 1; Figure 2). In this case, sound dentin was probably removed. According to the present results, when the carbide bur was used, initial carious dentin was overexcavated, and the MIP was higher (1.09 and 1.12, respectively, for digital and micro-CT images) than when the polymer bur (0.57 and 0.26, respectively, for digital and micro-CT images) was employed (Table 1). Hence, the second tested hypothesis must be rejected. The carbide bur usually overprepares carious dentin, also removing the caries-affected dentin.[3,16,20] The carbide bur presents a negative rake angle, which means that its blade is ahead of the perpendicular line to the surface being cut. To keep the blade in contact with this surface, increased downward pressure is needed, and this can lead to a less controlled movement of the instrument on the surface.[16] The speed of this rotary instrument and its mode of function may make this technique less sensitive and more difficult to control.[16]

Micro-CT is becoming increasingly popular in dental research, as it enables collecting detailed quantitative and qualitative data of the substrate before and after a specific treatment.[12,14,21-24] Its application in studying caries excavation techniques has recently been demonstrated by comparing the internal tooth structure before and after caries removal.[6,13,22,25] However, the use of micro-CT as an accurate tool for caries detection is controversial.

Mitropoulos and others[26] reported that micro-CT diagnosis was strongly correlated with some visual criteria but was not a reliable alternative to histological examination for caries research. The lack of correlation between these two diagnostic methods was attributed to the inherent deficiency of microtomography technology, similar to radiography, to detect early signs of demineralization.[26] Current results show that micro-CT is able to detect caries lesions before and after excavation, although high precision in lesion limits could not be observed.

Improvement in digital camera technology has allowed this technique to be used in several fields of science, as obtained images contain information that can be processed and analyzed.[15] Digital imaging presents several advantages. It is a low cost, easily available, nondestructive research technique that allows hard tissues to be measured and evaluated many times with samples remaining available after scanning for additional biological and mechanical testing.[15,27] Therefore, to assess caries removal methods, the digital image analysis tool was used to diagnose carious lesions. The present results demonstrate that digital photography seems to be a viable method for analyzing mineralized and carious dental tissues, as well as color alterations before and after caries excavation.

Although this study did not aim to compare caries detection methods, it is possible to note that there was a slight tendency of similarity between the digital image and micro-CT analysis.

Development of new conservative technology to remove caries and the improvement of those already available in the market represent a great challenge for researchers and manufacturers. Polymer burs represent important tools to preserve caries-affected dentin but still lack clinical evaluation and follow-up after caries removal and the restorations are placed. Diagnostic methods must also be studied and improved. The search for methods of diagnosis that are more precise, less invasive, and cheaper has been a constant concern in dentistry. More extensive analysis of both digital and micro-CT images is necessary to consolidate them as feasible and reliable diagnostic methods. New micro-CT devices and three-dimensional reconstruction seems to be very promising.

CONCLUSIONS

Within the limitations of this study, when either digital imaging or micro-CT analysis were employed, it was concluded that the carbide bur was the most effective method to remove carious dentin. In addition, the polymer bur presented low invasive potential but was not able to remove all carious dentin.

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Human Subject Statement

This study was conducted in accordance with all the provisions of the human subject oversight committee guidelines and policies at Universidade Federal do Ceará. The approval code for this study was 108/12 under protocol 54/12. This study was conducted at the Federal University of Ceará.

Conflict of Interest

The authors have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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