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An improved CVDD bur used in ultrasonic dental system for enamel removal

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Abstract

The aim of this paper is to increase enamel removal rate of dental diamond bur used in ultrasonic system so as to realize and promote its clinical applications. The cutting performances of the burs made by the electroplated diamond and by the chemical vapor deposition diamond (CVDD) are compared by experiment. It is found that the CVDD bur can achieve a higher removal rate. Detailed observation of the microphotograph of cut surface reveals that the superior performance of the CVDD bur is related to the morphology of the CVDD bur and the chips it produced. There are large amount of small cutting edges on the top of large size diamonds of the CVDD burs which results in tiny cutting chips. The materials along the plowed grooves left by the large size diamonds are removed by the adjacent small cutting edges. This action enables the cutting process to be carried out continuously rather than clogging the downward movement of the tool as experienced by the use of the electroplated diamond bur. But on the other hand, the too small chips also restrict the enamel removal rate. Hence a novel design of improved CVDD bur with fewer small cutting edges is proposed. The amount of cutting edges is reduced by heating the existing bur at 700°C for various time periods. It is found that the enamel removal rate along and perpendicular to enamel prism directions can be increased by 60% and 30%, respectively as compared with the untreated CVDD bur when it is heated in the nitrogen environment for 10 minutes.

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Keywords: ultrasonic dental system; enamel removal rate; CVDD bur; electroplated diamond bur

1. Introduction

Cavity preparations for dental filling are the initial clinical procedures for the treatment of decayed teeth by dentists. Currently, the high speed dental handpiece coupled with electroplated diamond (EPD) burs is most commonly used for this purpose. However, it is difficult to clearly observe the internal condition of oral cavity while operating because of its large size. Dentists must rely on their experience and feeling to accurately perform surgery.

Comparing with high-speed dental handpiece, the ultrasonic dental unit handpiece has a smaller front-end that provides the advantages of improved visibility during surgery, better differentiating capabilities for hard and soft tissues, and more tolerable for patients. Similar to high speed dental handpiece, EPD burs are generally connected to the ultrasonic handpiece for material removal. But the enamel removal efficiency for this tool is still very low that the ultrasonic dental unit coupled with EPD burs is not widely accepted by the dentists for cavity preparation so far. The chemical vapor deposition diamond (CVDD) coated burs were introduced in early 2000. Lima [1] investigated the cutting characteristics of cylindrical and spherical shapes CVDD burs, and found that precise and conservative cutting could be achieved. Carvalho et al. [2] also pointed out that CVDD burs coupled with an ultrasonic device was a promising alternative for preparing ultraconservative cavity. Lima et al. [3] showed that cavities prepared in enamel and dentin by the ultrasonic CVDD dental bur were

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shallower and narrower than those prepared with conventional diamond bur. Regarding material removal rate of CVDD dental burs, Bernardes et al. [4] claimed that CVDD burs exhibited better performance than the EPD dental burs based on the evaluation of three different ultrasonic diamond tips.

Even with various benefits of CVDD burs when they are coupled with the ultrasonic dental unit, low cutting efficiency is still a major limitation [5]. Vanderlei et al. reported that it required 4 times longer as compared with the high speed dental unit in completion of a cavity preparation [6]. This indicates that the material removal rate of CVDD dental burs, especially in processing enamel, is still a crucial issue. Hence, the objective of this paper is to understand the enamel removal mechanism of CVDD dental burs, and to propose an improved bur to enable the ultrasonic dental devices to be more practical for clinical applications.

In the paper the cutting performances of the commercially available EPD and CVDD dental burs are first compared. Microphotographs of the morphology of the CVDD bur and cut surface are studied in detail. Based on the inferred enamel removal mechanism of CVDD burs, approaches to create improved CVDD burs are proposed. Actual cutting tests are conducted to verify the effectiveness of the newly developed burs.

2. Experiment

The Piezoelectric Ultrasonic Surgery Unit by VIA-Tech Biomedical Co., Ltd, Taiwan was used in this study (Fig. 1(a)). It vibrated at frequencies range of 26-30 kHz, with a 30 VA of power when in cutting, and a pump enabled a 10 mL/min flow rate of water for flushing. The experiments were conducted on a self-designed and assembled 3-axis motion platform (Fig. 1(b)). The ultrasonic dental headpiece was fixed on the Z axis. The platform could slide back and forth in the X-axis direction, which allowed the grinding tests on the tooth specimens to be performed. The force in the Z direction of the headpiece was provided by a voice coil motor so that downward pressure during dental surgery could be simulated. The CVDD ultrasonic dental bur (R2, CVDentus, CVDVale, Brazil) shown in Fig. 1(c) was used. For comparison purpose the EPD bur (UL3A, VIA-Tech Biomedical, Taiwan) (Fig. 1(d)) was also tested. The surface morphologies of these two burs are shown in Fig. 2(a, b) and Fig. 2(c, d), respectively. The size of the diamond is approximately 100 μm for the CVDD bur. The protrusion (tumor-like) height is about 50-60 μm. In addition, there are many small diamonds with a size of about 10 μm on the top surface of the protruded diamonds. For the EPD bur, the diamonds exhibit more intact crystal structure. The diamond size is about 90 μm. The number of diamonds on the surface is

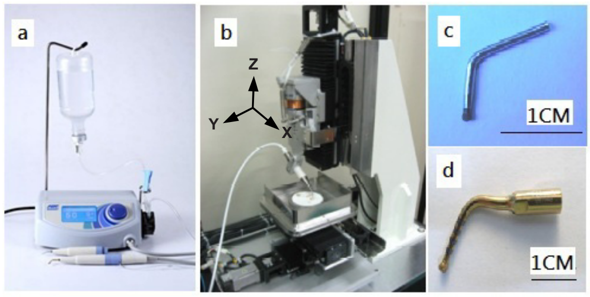


Fig. 1. (a) Ultrasonic Surgery Unit (VIA-tech), (b) 3-axis motion platform, (c) The CVDD ultrasonic dental bur (CVDentus), (d) The EPD dental bur (VIA-TECH).

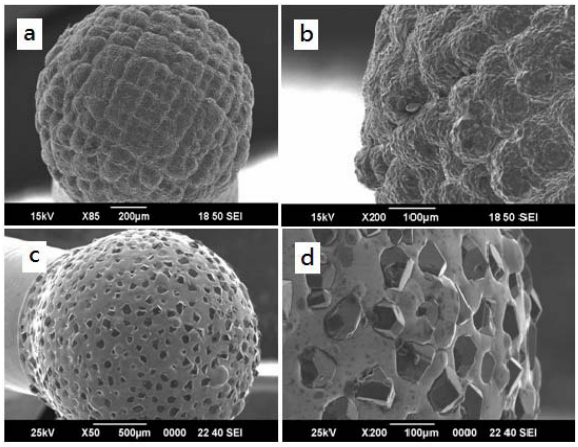


Fig. 2. Surface morphology of the ultrasonic dental bur. (a) CVDD bur, (b) larger magnification of the CVDD bur, (c) EPD bur, (d) larger magnification of the EPD bur.

approximately 45 particles per square millimeter, and the protrusion height is about 30-40 μm. The cavity depth was measured by the laser scanning confocal microscope (VK9700, Keyence, Japan), and volume of the cavity was computed by the provided software.

The molars and lateral incisors from adults were used in the grinding tests so that the performance of the dental burs along and perpendicular to enamel prism can be evaluated.

3. Material removal mechanism

The cavity depth after grinding the molar specimen for 30 seconds for the two types of burs is shown in Fig. 3. It can be seen that the CVDD dental bur leads to a deeper cavity, or a larger material removal than the EPD bur. The microphotographs of the surface ground by these two types of burs are shown in Fig. 4(a) and 4(b), respectively. The deep grooves are left on the surface ground by the EPD bur, and a comparatively smoother surface is obtained by using the CVDD bur.

To understand the material removal mechanism of CVDD dental burs, the molar specimen is scrapped by a CVDD bur under 2 N down force, without ultrasonic vibration, and no flushing condition. The scrapped surface and the bur after scrapping are shown in Fig. 5(a) and Fig. 5(b), respectively. It can be seen that there are small scratched marks within the surface being scrapped. Hence in cutting the protruded large diamonds on the surface of the CVDD bur would penetrate into the tooth first when the load is applied. This is followed by actual material removal by the small size diamonds on top of large size diamonds. It is noted that there are very small chips left on the bur surface (Fig. 5(b)). These tiny chips suggest that the material is cut into very small pieces during the process. The foregoing material removal mechanism does not apply for the EPD burs. In this case the chip pocket (space between two diamonds) which is covered by the nickel layer could be in contact with the tooth after the protruded diamonds have penetrated into the material. The cutting ability of nickel layer is negligible since it is relatively soft as compared with enamel. Hence the downward movement of the bur becomes difficult because the bur is blocked by the un-removed material. As a result, the material removal process is retarded, and deep grooves on the ground surface are generated.

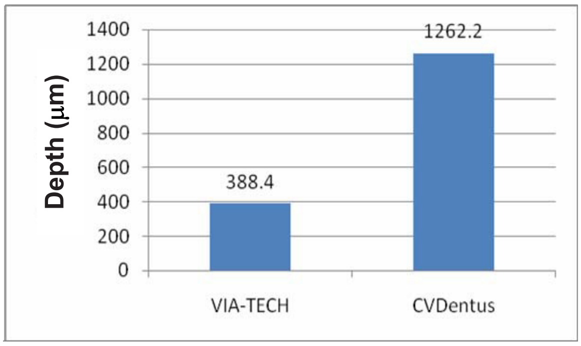


Fig. 3. Depth of cavity ground by the EPD and the CVDD dental burs.

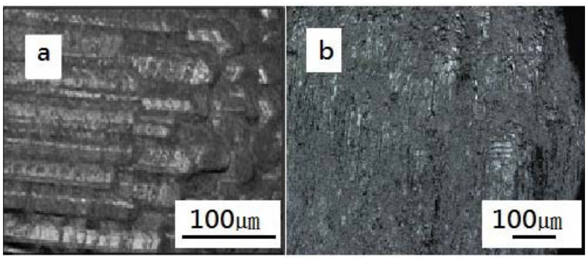


Fig. 4. Surface of the tooth specimen, (a) ground by an EPD dental bur (b) ground by a CVDD dental bur.

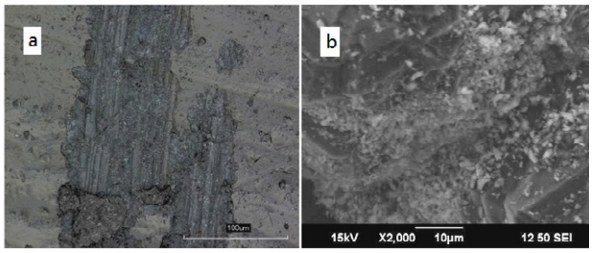


Fig. 5. (a) Scratches on the surface of the molar specimen scrapped by a CVDD dental bur. (b) The tiny chips left on the dental bur.

4. Improved CVDD burs

Based on the results given in the last section it is noted that the chips produced by CVDD dental burs are very small. This is due to many small cutting edges (diamonds) on top of the large diamonds. Since the material removal rate is closely related to chip size, it is expected that the material removal rate can be improved by increasing chip size. In other words, reduction of the number of cutting edges of the CVDD bur is beneficial to enamel removal.

In order to realize this inference, heating of the original CVDD burs so as to reduce the number of cutting edges is proposed. The first approach is by heating CVDD burs in air so that some of the cutting edges can be removed via oxidation of diamond. Morphologies of the CVDD burs heated in air for 5, 10, and 15 minutes are shown in Fig. 6(a)-Fig. 6(c). There is no significant change of the surface morphology except that the cutting edges are becoming less sharp as the time of heating is longer. Alternatively, CVDD burs are heated in nitrogen. The idea is that the diamond would burst due to volume change at a higher temperature when there are impurities in the diamond, and at the same some of the small cutting edges are removed as a result of diamond explosion. Fig. 6(d)-Fig. 6(f) are the surface morphologies of the CVDD burs heated in nitrogen for 5, 10, and 15 minutes. As it can be seen from these figures, the number of cutting edges is indeed decreased with the increase of heating time as expected. However, it should be noted that the sharpness of the cutting edge is not affected. It remains almost the same as that before heating.

The cutting efficiency in this study is evaluated in terms of material removal rate (MRR). The MRRs in grinding molar specimens by the use of improved burs are given in Fig. 7(a). The removal rate by using the original CVDD dental bur is also included for comparison. As depicted in the figure, satisfactory results are obtained. There is 25% increase of removal rate for the CVDD burs heated in air for 15 minutes. More attractive results are achieved when CVDD burs

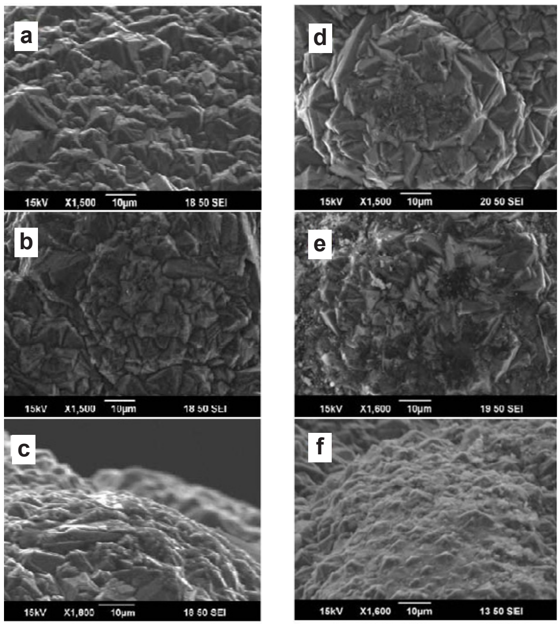


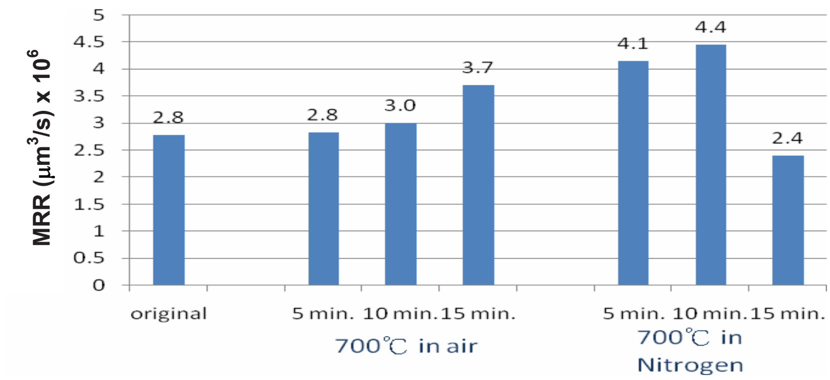
Fig. 6. The bur after heating in air for (a) 5 minutes, (b) 10 minutes, and (c) 15 minutes. The bur heated in nitrogen for (d) 5 minutes, (e) 10 minutes, and (f) 15 minutes.

are heated in nitrogen. A 50% increment is obtained when the bur heated for 5 minutes is used, and as high as a 60% increase of the removal rate can be achieved by the improved bur which is heated in nitrogen for 10 minutes. It is noted that the CVDD bur heated in nitrogen for 15 minutes does not lead to a better performance. This could be due to too few cutting edges are left for material removal as a result of too long heating time.

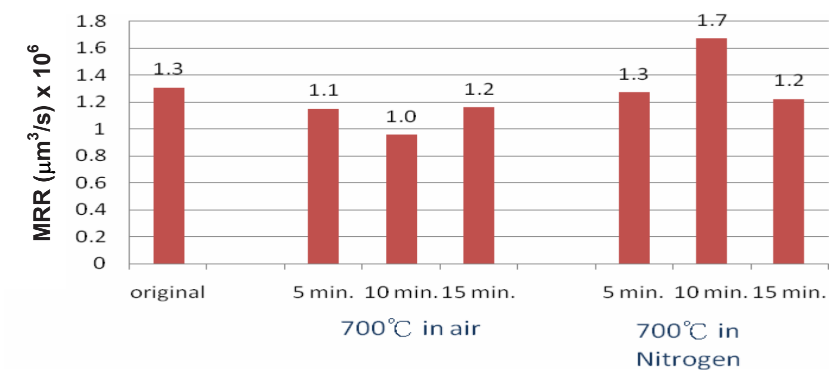
The results in grinding buccal sides of lateral incisor specimens are shown in Fig. 7(b). The increase of material removal rate is not as promising as that in grinding molar specimens. Nevertheless, the use of the bur heating in nitrogen for 10 minutes still leads to a 30% enhancement of removal rate.

5. Conclusion

The CVDD dental bur coupled with an ultrasonic dental unit performs better than the EPD bur, and this is closely related to the morphology of the CVDD bur and the chips it produced. The mechanism of enamel removal of CVDD dental burs is clarified. The large



(a)



(b)

Fig. 7. Material removal rate for the heated dental burs. (a) In grinding molar specimens, and (b) in grinding buccal sides of lateral incisor specimens.

protruded diamonds penetrate into the enamel first, and the small cutting edges of small diamonds atop of the large diamonds are responsible for material removal. The dental bur works better when it is operated along the growth direction of enamel prism than perpendicular to this direction. Approaches to improve enamel removal rate of the dental bur have been proposed. The CVDD bur heated to 700°C in air is not effective since the cutting edges are dulled as a result of diamonds oxidation. Heating of CVDD burs in nitrogen leads to very satisfactory performance. The removal rate can be increased by 60% and 30%, respectively when the improved bur obtained by heating the original CVDD dental bur in nitrogen for 10 minute is used for grinding molars and incisors.

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