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Micromorphologic assessment of CVD (chemical vapor deposition) and conventional diamond tips and their cutting effectiveness

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Abstract The aim of this study was to compare the micromorphology of CVD diamond tips coupled to ultrasound with conventional high speed diamond tips after cavity preparations, and to measure the width and depth of the cavities obtained. Two hundred bovine teeth were divided into 20 subgroups. Each of the diamond tips (10 CVD and 10 conventional) were used to prepare 10 standardized cavities, using an apparatus that controlled the time (t: 27 s), speed (5.3 mm/s) and load (0.012 KGF) of the tip against the teeth during preparation. The unused and the used (after one, five and 10 preparations) tips were analyzed by scanning electronic microscopy. The images were randomly assessed by 3 examiners with regard to the presence or absence of micromorphologic alterations. Cavity measurements were made after visualization under a stereoscopic microscope. Cavity widths and depths were analyzed by the ANOVA Factorial test ($p < 0.05$). The CVD diamond tips presented less wear than the conventional tips after all the cavity preparations performed, but produced shallower cavities that were equivalent in width to those made by conventional tips after the fifth preparation. CVD diamond tips may be suggested as an alternative to conventional diamond tips due to their conservative preparation and greater longevity.

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Introduction

Since dentistry burs and diamond tips were introduced, significant advance in research has enabled increasingly efficient methods and instruments to be developed for cutting dental tissue [1–4].

The first rotary cutting instrument to be used in Dentistry was the diamond tip developed at the end of the 19th century [5–7]. However, in spite of instrument enhancement, the technology for manufacturing these conventional tips is still limited by the heterogeneity in the shape of the diamond granulations, the difficulty of automating tip manufacture and their low durability [8–12].

At the end of the 20th century, after modifications and improvements, ultrasound became multifunctional, and could be used to prepare cavity preparations in association with a CVD—Chemical Vapor Deposition—diamond tip [13–17]. CVD technology applied to diamond tip manufacture for use in dentistry, enabled the grains to adhere sufficiently to the metal shaft to withstand the effect of ultrasound, thus providing an alternative technique to high speed for cutting dental tissue. These tips are made with a molybdenum substrate material that allows a continuous CVD diamond film to grow without a metallic binder between crystals. For bur manufacturing, the substrate of choice has to present a higher fusion temperature than the temperature required for the diamond growth (generally, higher than 800 °C), a thermal expansion coefficient comparable to that of the diamond, as well as the property of carbide formation [19–22].

CVD diamond tips provided a way of overcoming some of the deficiencies of conventional diamond tips, and the main purpose was to offer more durable tips, since the deposition of this diamond occurs without requiring auxiliary methods to promote adhesion [18, 20]. However, there is little information in the literature about their performance.

Thus, the aim of this study was to assess the surface micromorphology of the CVD and the conventional diamond tips after cavity preparations and to compare the width and depth measurements of the cavities obtained.

Method and materials

About 200 healthy bovine mandibular central and lateral incisor teeth, stored in a 0.1% thymol solution from the moment of extraction after the animal had been slaughtered, were used in this study. They were debrided with periodontal curettes and scalpel blades and stored in a fresh solution of 0.1% thymol. Teeth with fractures or depressions that did not allow preparation in the medium-median third of the vestibular face were excluded from the study. The coronary portion was delimited with graphite and fractioned in an ISOMET cutting machine, so that only the medium-median third of the tooth, measuring approximately 0.7×0.7 mm, remained. The palatal face was embedded in self-polymerizable acrylic resin (OrtoClass/Clássico Ltda) in a PCV tube 1 cm high and 2 cm in diameter, leaving the vestibular surface free and parallel to the horizontal plane.

Standardized cavity preparations were made on the vestibular surface of the teeth with 2 different instruments, the CVD and the conventional diamond tips, in accordance with Table 1.

To standardize the cavities, an electro-mechanical device, which could be coupled to both a high-speed turbine and ultrasound appliance (Fig. 1), was used. It also controlled the time (27 s), speed (5.3 mm/s) and the pressure (0.012 KGF) of the tips against the tooth during preparation.

The CVD diamond tips were adapted to the ultrasound appliance (Prof I AS/Dabi Atlante) by means of a specific connector (code UA3), and the power was adjusted to correspond to 50% of the total amplitude of tip vibration with minimum irrigation. Cavity preparation was done by moving the tip in the same direction as the vibration generated by the ultrasound (antero-posterior direction), forming a 90° angle between the active part of the tip and the tooth face.

The conventional diamond tips were coupled to a high-speed turbine (Roll Air 3/Kavo). The direction, position, speed, pressure and number of movements to make the preparation were similar to those previously described.

The samples were randomly and equally divided between the types of tips. Ten conventional cylindrical diamond tips (KG Sorensen) and 10 cylindrical CVD diamond tips (CVDentUS/Clorovale Diamantes) initially new (unused), served as control group. Each of these tips performed a sequence of one, five and 10 cavity preparations. After each cavity was made, the corresponding tip

Table 1 Informative data on diamond tips analyzed in this study

Tip name	Manufacturer	Shape	Coupling system	Tip measurements
Diamond Tip No. 1092	KG Sorensen	Cylindrical	High Speed	1 mm diameter/4 mm active tip
Diamond Tip CVDentuS Code 82137	UC—Dentistry	Cylindrical	Ultrasound	1 mm diameter/4 mm active tip

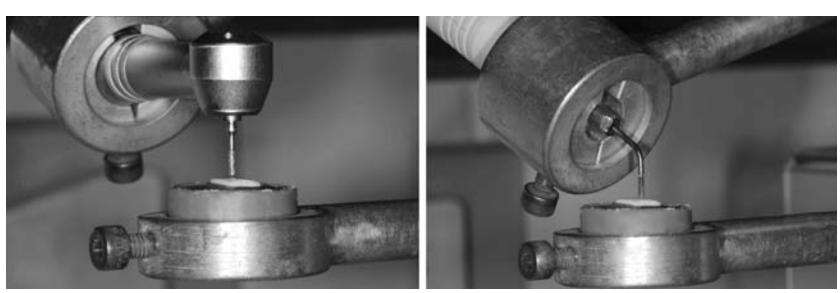

Fig. 1 High-speed turbine and ultrasound appliance coupled to preparation machine

was cleaned with a burr brush (JON/J.O.N. Comércio de Produtos Odontológicos Ltda) imbibed in enzymatic detergent (Riozime II/Rioquímica) to remove the debris.

Each tip was photomicrographed, always on the same face at the extremity of the active tip (region corresponding to the cutting action of the tip) before being used and after one, five or 10 preparations had been performed. A scanning electronic microscope (DSM 940 A/ZEISS) was used at 100× magnification. The tip images were numbered from 1 to 80 and randomized for wear assessment by three calibrated examiners in a blind study, in accordance with the following criteria: N (no) = shape of the tip outline whole, with the presence of the adherent diamonds, without presenting wear of the metal constituent of the tip. S = presence of wear or removal of diamond crystals, alteration in tip shape and wear of the metal that constitutes the tip.

The cavities corresponding to the 1st, 5th and 10th preparation made with each type of tip were cross-sectioned with a cutting machine (Isomet 1000), to obtain two sides of each cavity (A and B). Next, the samples were positioned on a glass slide with utility wax and observed under a stereoscopic loupe at 50× magnification.

The images obtained with the stereoscopic loupe were captured by a digital camera and transferred to a computer by means of the ''Leica Qwin'' program, which allowed the width and depth to be assessed, in a blind study, after the image was calibrated by means of the 500 μm bar provided by the photomicrograph. The data obtained were statistically analyzed by the ANOVA Factorial test at a 5% level of significance.

CVD and conventional diamond tip manufacture

The CVD diamond growth process consists of activating a mixture of a gas composed of small amounts of hydrocarbons diluted in hydrogen by different methods. This gas activation produces atomic hydrogen and hydrocarbon radicals—especially the methane radical (CH_3) without conditions of thermodynamic equilibrium. The crystalline diamond web grows by the incorporating carbon atoms from the hydrocarbons of the gaseous phase. The most used activation processes are those assisted by plasma generated by microwave (*MWCVD*), hot filament (*HFCVD*), acetylene and oxygen chamber (*ATCVD*) and by plasma jet (*AJCVD*). Hydrogen is the most critical component during the gaseous phase of the mixture, because it guides the chemical process. During growth, the diamond surface becomes hydrogen saturated. This coverage limits the number of the places where the hydrocarbon molecules (CH_3) may be absorbed, in addition to blocking the places where they can adhere. A hydrogen atom (H) binds to another hydrogen atom (H) on the surface to form H_2, leaving a reactive place on the surface. The easiest process would be for another union to occur with free hydrogen. Occasionally, methane (CH_3) may collide and react with the surface. This process may repeat itself in an adjacent place and another hydrogen radical originated by any other group may bind next to the carbon groups, completing the ring structure. In other words, the diamond growth may be considered a process of carbon deposition on a diamond surface due to the excessive presence of hydrogen atoms [24]. According to the manufacturer, CVD diamond tubes may be developed in many dimensions. They may range from about 0.2 mm to several millimeters in diameter, whereas each layer of their coating thickness may range from 60 to 80 μm. The diamond is crystalline with grains of around 50 μm. It is a unique diamond formed by the deposition of the grains. The abrasiveness is given by the grain size and by the layers deposited. The quality of the CVD diamond film depends directly on the flow control of the mixture, temperature on the substrate, temperature of the filament and internal pressure of the reactor [19].

According to the manufacturer, the conventional KG Sorensen diamond burs for dental and laboratory use are produced with highly resistant stainless steel material and with natural diamond grains of controlled dimensions. For bur No. 1092, the grain varies in a mean range of 91–126 μm. Conventional diamond burs—using both natural and/or synthetic diamonds—are manufactured in multiple layers by electrodeposition, sintering or microbrazing, and in principle, the cutting surface is continually regenerated as wear occurs [7].

Results

The degree of intra and inter-examiner agreement was estimated by the Kappa index at the two stages of interpreting the photos under a microscope. According to the interpretation of Kappa values suggested by Landis and Koch [23], the indexes presented ranged between moderate to good standards ($0.59 < K > 0.67$), thus the examiners answers were considered.

The Exact Fisher test showed a significant difference in micromorphology among the conventional and CVD diamond tips from the first time they were used (Table 2 and Fig. 2).

With regard to Fig. 2, which shows the presence of wear of the conventional diamond tip as a result of the number of preparations performed, 40% of the instruments showed gaps in the active tip, suggesting the absence of diamond before they were used. In addition to the presence of locks without diamond chips, signs of wear were noted in 70% of the tips after the 1st preparation. This percentage increased

Table 2 Proportion of visual wear on tips for each time of use

Type of tip	Number of preparations							
	0		1		5		10	
	Criterion							
	N	S	N	S	N	S	N	S
Conventional	6	4	3	7	2	8	0	10
CVD	10	0	9	1	9	1	8	2
p-value (Fisher)	$p = 0.0867$		$p = 0.0198$		$p = 0.0055$		$p = 0.0007$	

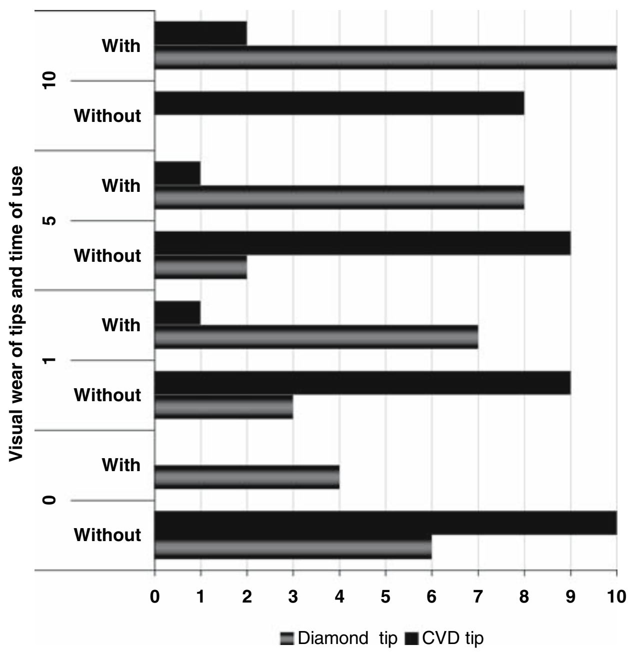

Fig. 2 Proportion of visual wear on tips for each time of use

to 80% of tips with morphologic alteration at the 5th preparation, and by the end of the tenth preparation, all the tips were worn. With regard to wear, the CVD diamond tips presented better results than the conventional diamond tips. After the 1st preparation, it was noted that 10% showed wear, and remained at this stage until the 5th preparation. After 10 preparations, wear was noted in 20% of the tips tested (Figs. 3, 4).

With regard to cavity sizes, the ANOVA factorial test was applied, and the results are shown in Fig. 5 and in Tables 3 and 4. According to Tables 3 and 4, the results showed that there was no statistical difference in the widths of cavities made by the conventional diamond tips from the first to the tenth preparation. This result was also checked as regards the width of the preparations made with the CVD diamond tips. The comparative analysis of the cavity widths produced with the two types of tips showed statistically significant differences only in the first preparation, with the highest mean values obtained for the conventional diamond tips.

With regard to the height of cavities made with the control tips, the cavities from the 1st to the 5th preparation differed significantly from the 10th preparation, the latter presenting the highest mean values. The experimental tips did not present any statistically significant difference when the height of the cavities was assessed during the course of the experiment. When the height of the preparations made with the diamond tips were compared with those made with the CVD diamond tips, statistically significant difference was shown at all preparation times with the highest values attributed to the control tips.

Discussion

The scanning electron microscopy analyses showed that depending on the type of diamond tip used, the morphologic characteristics of their surfaces underwent alterations after successive cavity preparations.

The studies conducted by Freire et al. [4], Grajower et al. [5], Janota [8], Steagal and Garone Netto [10] and Beatrice [11] showed that the conventional tips presented abrasion and detachment of the diamond particles, corroborating the results found in the present study.

In the initial analyses before the tips were used, some of the conventional tips presented regions with absence of diamonds. This represents one of the limitations of this material, such as the difficulty of automating [12] its manufacture, thus escaping quality control. Quality control during the electro-deposition process is the most important aspect of the overall tip manufacturing process, and varies in accordance with the operating conditions that must be strictly controlled. If the pH and the temperature are not balanced, there may be a failure in the deposition of diamond fragments on the active tip surface, causing a random distribution of the diamonds that does not fill all the necessary spaces. Moreover, the time spent on the process of diamond deposition on the active tip may also influence the quality of the diamond tip [2].

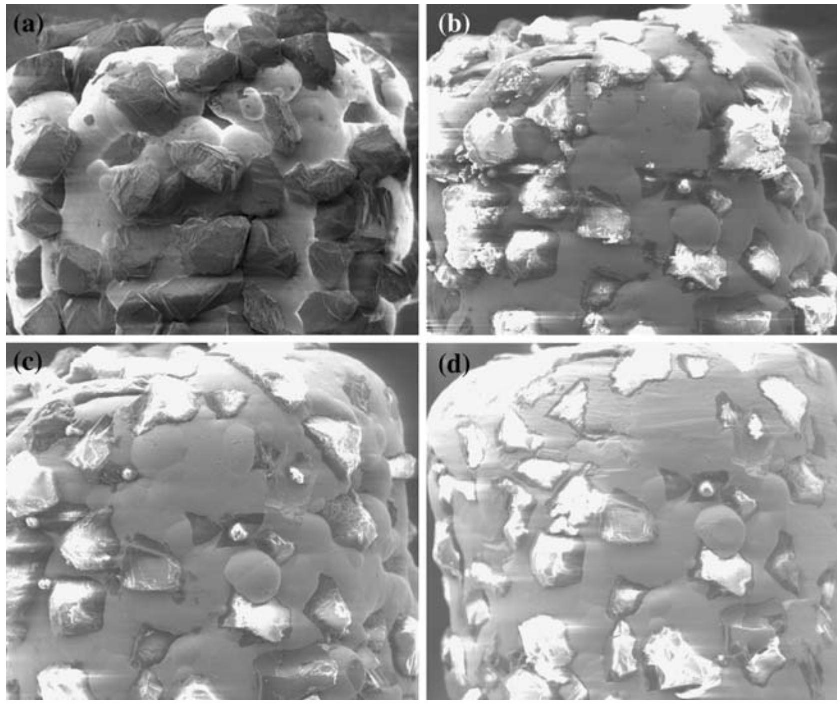

Fig. 3 Micromorphology of conventional diamond tips: (**a**) Unused Tip; (**b**) After 1 preparation; (**c**) After 5 preparations; (**d**) After 10 preparations

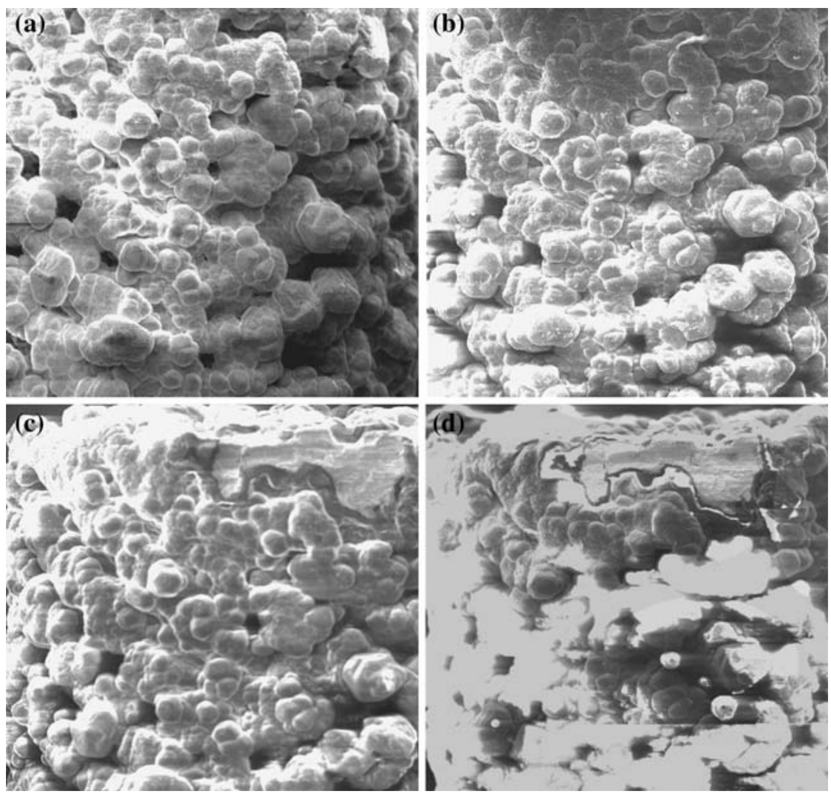

Fig. 4 Micromorphology of CVD diamond tips with alteration. (**a**) Unused Tip; (**b**) After 1 preparation; (**c**) After 5 preparations; (**d**) After 10 preparations

Some variables, such as the nature of the diamond or material that constitutes the bur [1], the process used for fixing the diamond grain to the shaft [4] and the amount of nickel deposition on the tip [3, 7] may have influenced the loss or wear of conventional diamond tips. According to Correa [3] and Siegel and Von Fraunhofer [7], if there is insufficient nickel deposition on the tip, there would be a premature loss of the diamond fragments as the result of inadequate bonding with the metal matrix.

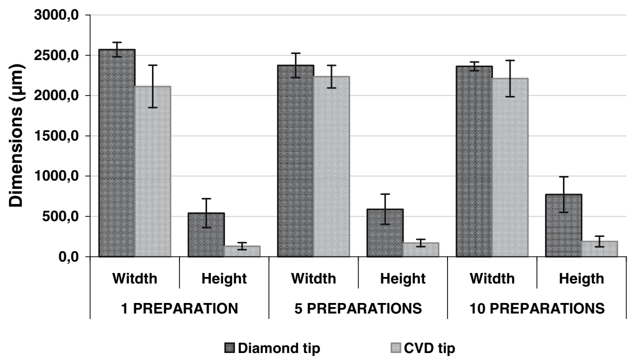

Fig. 5 Cavity preparation dimensions as a result of the type of tip and time of use of tips

The comparison between the two types of tips, with varying numbers of preparations, showed a smaller number of worn CVD diamond tips in comparison with the conventional diamond tips used at high speed, probably due to the form of diamond deposition on the metal shaft.

However, in two of the CVD diamond tips there was detachment of part of the diamond layer that covers the shaft. A failure in the substrate surface treatment may prevent adequate growth of the diamonds on the substrate used, thus harming the chemical bond between them and promoting diamond film detachment. According to Trava-Airoldi et al. [19], adherence between the diamond and the metal depends on how adequately the interface is prepared.

When analyzing the width of the cavity preparations made with the conventional tips, no statistically significant difference was observed from the 1st to the 10th preparation. With regard to the height, the cavities from the 1st to 5th preparation differed significantly from the 10th preparation, the latter presenting the highest mean values. This may be explained by the behavior of the conventional instruments that are coated by many abrasive tips and are generally not arranged in an orderly pattern, with the diamonds having several orientations. Each diamond fragment acts as an individual blade and removes a portion of the material from the surface without penetrating deeply into the tooth [5]. As these various cutting tips are randomly destroyed during the course of the preparations, the tip becomes more regular, consequently producing cavities with a more defined geometry and greater depth [6].

The experimental tips did not present any statistically significant difference when the height and width of the cavities was assessed during the course of the experiment. Probably, due to the homogeneous morphology of the CVD diamond tips, with the appearance of completely coalesced columns forming a single diamond stone [14, 18], they provided the same type of wear over time, and remained unaltered during all the preparations.

When the height of the preparations made with the conventional diamond tips were compared with those made with the CVD diamond tips, statistically significant differences were observed at all analysis times with the highest values attributed to the conventional tips.

According to O'Brien and Ryge [9], the irregular shaped particles with sharp edges present on the conventional diamond tips, produce faster abrasion of a surface with deeper grooves, than the particles with rounded edges that constitute the CVD diamond tips, which would explain the results found.

In spite of the few studies evaluating CVD diamond tips, a previous study conducted by Predebon et al. [17] assessed the use by dentists of these tips accredited by the CVD system. This study showed that approximately half of the professionals consider the final form the preparation made with CVD diamond tips to be more conservative when compared with the high-speed diamond tips. This

Table 3 Width of preparation as a result of the type of tip and time of use

	Width		
	1 preparation	5 preparations	10 preparations
Diamond tip	2570.0 ± 90.2 Aa	2373.6 ± 151.2 Aa	2362.5 ± 54.2 Aa
CVD tip	2113.0 ± 262.9 Ab	2234.6 ± 140.8 Aa	2211.3 ± 225.3 Aa

Different letters (capitals in the horizontal and lower case in the vertical) differ among them by ANOVA ($p < 0.05$)

Table 4 Height of preparation as a result of the type of tip and time of use

	Height		
	1 preparation	5 preparations	10 preparations
Diamond tip	541.0 ± 178.7 Ba	588.7 ± 187.5 Ba	770.8 ± 220.2 Aa
CVD tip	130.5 ± 43.3 Ab	169.9 ± 44.5 Ab	189.6 ± 65.8 Ab

Different letters (capitals in the horizontal and lower case in the vertical) differ among them by ANOVA ($p < 0.05$)

conservative characteristic of the preparations was clearly expressed in the present study.

Conclusion

Chemical Vapor Deposition diamond tips coupled to ultrasound may be an alternative to conventional diamond tips used at high speed, due to their conservative action during the procedure, as well as their greater longevity.

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