Microscopic changes on morphology of diamond coated dental burs as consequence of multiple uses

Isabel Cristina Celerino de Moraes Porto *, José Cláudio Correia**, Samuel Barbosa da Silva Filho #

* PhD, Professor of Restorative Dentistry, School of Dentistry, Cesmac University Center, Maceió, Alagoas, Brazil.
** BDS, School of Dentistry, Cesmac University Center, Maceió, Alagoas, Brazil. # Undergraduate Student, School of Dentistry, Cesmac University Center, Maceió, Alagoas, Brazil.

Address for correspondence: Isabel Cristina Celerino de Moraes Porto, School of Dentistry, Cesmac University Center - Rua Cônego Machado, 918, Farol, CEP: 57051-160, Maceió, Alagoas, Brazil

Mob: 55 82 3215 5031 Fax: 55 82 3215 5214
Email: isabel.porto@cesmac.com.br / isabelcmporto@gmail.com

Abstract: Objective: This study evaluated the wear of diamond burs after successive cavity preparations. Materials and Methods: For this purpose, eighty bovine incisors and thirty diamond burs (KG Sorensen) were used. The diamond burs were analysed using a scanning electron microscope (SEM) to evaluate the degree of wear before use and after the first, fifth and tenth cavity preparation under constant refrigeration. Scores ranging from zero to four were awarded to the specimens by two calibrated examiners according to the degree of wear found (Kappa = 0.81). The bur wear results were analysed using the Kruskal-Wallis test ($\alpha = 0.05$). Results: SEM revealed that the studied burs showed different and increasing degrees of wear and loss of diamond particles as they were subjected to a larger number of cavity preparations, with significant differences among all groups evaluated. The use of diamond burs after the fifth preparation is questionable. Conclusions: After the tenth cavity preparation, the diamond burs showed severe wear and loss of diamond particles, with exposure of large areas of the metal rod. This number of reuses must therefore be avoided.

Keywords: dental instruments; dental instruments/use; permanent dental restoration/instrumentation.

INTRODUCTION
The emergence of new materials, techniques and general knowledge has transformed dentistry over time. However, certain aspects have changed little over the past 100 years, and rotary instruments have remained the technique of choice for cavity preparation since the work of the ground-breaking pioneer GV Black, although other techniques, such as air and laser abrasion and the chemical removal of caries, have been suggested(1,2).
Most dentists still use traditional high-speed drills for most of their clinical work. Furthermore, the design of the dental drill bit has changed little during the same period, despite advances in technology and the science of abrasive materials in general. The question is whether the more mechanical aspects of dentistry, notably cavity preparation, have fully benefited from recent technological growth. This issue is complex because many factors affect dental cutting, particularly the nature of tooth preparation itself, individual variations in dental practice and the great variability in dental hard tissue. Another complicating factor is the intrinsic variability within all types of manufactured products, such as drills, diamond burs and handpieces (3).

The creation of the first diamond burs, in 1897, is credited to Willman and Schroeder of the University of Berlin. However, it was only in 1932 that WH Drendel developed the process of joining diamond fragments to stainless steel rods that was the forerunner of the system currently employed (4).

Diamond burs are widely used abrasive rotary instruments for the removal of carious tissue and cavity preparation. The active tip of the bur consists of abrasive diamond particles, which are fixed by electroless nickel plating onto a small diameter cylindrical metal matrix. The active part of these instruments has, as an intrinsic feature, a very rough surface that facilitates cutting efficiency during the use of the instrument (5).

These rotary instruments have made significant advances possible in dentistry by performing procedures in a shorter operative time. Currently, knowledge of the various advantages of using diamond burs is well established (6).

Wear efficiency can be defined as the ability to remove as much tooth structure as possible in the minimum time and with minimum effort, without generating frictional heat, thus maintaining pulp integrity (3). For this purpose, the instrument must retain its physical characteristics, i.e., must provide wear efficiency.

The wear ability of the diamond bur is influenced by dental tissue fragments, restorative materials, saliva, blood products and microorganisms that tend to become compacted between the diamond particles. Usage time reduces the roughness of the diamond bur, which along with possible residue in its active part, means that the dentist needs to apply increased cutting pressure. This increased pressure can cause damage to the pulp and decrease the roughness of the tooth wall, which can lead to microleakage in the resin composite restorations (7).

Given the uncertainty of how many times diamond burs can be reused efficiently, this study aimed to evaluate the degree of wear of diamond burs after successive cavity preparations on bovine teeth.
MATERIALS AND METHODS

The study was done in accordance with the ethical principles originating in the Declaration of Helsinki and after approval by the Ethics Committee on Animal Use.

Eighty bovine incisors that had been extracted immediately after slaughter were used. They were kept in 2% glutaraldehyde for 24 h and then cleaned to remove debris and exogenous stains by scraping with periodontal curettes and by coronal polishing with pumice (SS White, Rio de Janeiro, RJ, BR) and water. They were then sectioned in the apical third with a diamond bur No. 1092 (KG Sorensen, Barueri, SP, BR) to permit the removal of dental pulp with the aid of Hedstroem files (Dentsply-Maillefer Instruments SA, Ballagues, Switzerland). After external cleaning and removal of the pulp, the teeth were kept in distilled water at 4°C until use.

Cylindrical diamond burs No. 1092 (KG Sorensen, Barueri, SP, BR) with particles of coarse-grained natural diamond (91 µm - 126 µm) were used at high speed and under intense cooling water to perform Class V cavity preparation on buccal and lingual surfaces of the teeth. Standardised cavities were prepared by a single operator and had the following dimensions: 4 mm wide, 3 mm height and 2 mm depth measured with the aid of a Williams type millimetre probe (SS White Duflex, Rio de Janeiro, RJ, BR). The diamond burs were analysed after the 1st, 5th and 10th preparation.

Eighty samples were separated and divided into three groups according to the number of times that the diamond bur was used: G-I: New diamond burs, no preparation; G-II: Diamond burs used only once; G-III Diamond burs used five times; G-IV: Diamond burs used ten times. After each preparation session, the diamond burs were cleaned by ultrasonic washing, dried with absorbent paper and reused without sterilisation.

When all preparations were completed, the diamond burs were analysed by scanning electron microscopy (SEM) model JSM 5310 (Jeol Ltda, Akishima, Japan) and photomicrographed to assess wear. They were ranked according to the scores reported in Table 1. The photomicrographs were analysed by two independent and previously calibrated evaluators.

<table>
<thead>
<tr>
<th>Scores</th>
<th>Description</th>
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<tbody>
<tr>
<td>Score 0</td>
<td>Absence of wear of diamond bur</td>
</tr>
<tr>
<td>Score 1</td>
<td>Change in shape of diamond particles</td>
</tr>
<tr>
<td>Score 2</td>
<td>Change in shape and some loss of diamond particles without exposure of metal</td>
</tr>
<tr>
<td>Score 3</td>
<td>Loss of diamond particles with partial exposure of metal</td>
</tr>
<tr>
<td>Score 4</td>
<td>Loss of diamonds with complete exposure of metal</td>
</tr>
</tbody>
</table>

Table 1: Classification scores for wear of diamond burs after preparations
Intra-examiner reliability was obtained using STATA statistical software by computing weighted kappa. The value of weighted kappa was 0.81. This kappa was in an acceptable range that indicated an unacceptable level of consistency. Kappa statistic showed acceptable intra examiner reliability. The Kruskal-Wallis test with pairwise test comparisons ($\alpha = 0.05$) was used for data analysis, employing SPSS (Statistical Package for the Social Sciences) software version 15 (IBM SPSS Inc., Chicago, Illinois, USA).

RESULTS

The frequency distribution of the diamond bur wear scores evaluated for each group can be observed in Figure 1.

![Figure 1: Percentage distribution of degree of wear according to number of preparations.](image1)

Figure 2 shows the mean scores for degree of wear of the diamond burs according to the number of preparations. For a fixed margin of error (5.0%), the Kruskal-Wallis test showed a significant difference between numbers of preparations in relation to degree of wear ($p < 0.05$), and pairwise comparisons demonstrated a significant difference between all pairs of groups.

![Figure 2: Distribution of scores (mean and standard deviation) for observed wear according to number of preparations.](image2)

The successive use of the same diamond bur for cavity preparation caused wear, evidenced by a change in shape and loss of diamond particles (see Fig. 3). Figure 4 illustrates the different wear patterns observed in the diamond burs evaluated in this work.

![Figure 3: 3A: New diamond bur showing diamond particles, with live angles over the entire surface (white arrows) attached to the base of the metal rod; 3B, 3C and 3D: Severe wear(white arrows) and loss (black arrows) of diamond particles.](image3)

DISCUSSION

This study evaluated the degree of wear of diamond burs used for cavity preparations in dentistry. Such studies are not new (1,8), however, they are very important for
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analysing the performance of diamond burs after successive preparations and to periodically record the performance of these instruments.

This analysis is necessary for clinical dentistry due to constant changes introduced by manufacturers and the need for these instruments to perform their function without damaging the pulp.

Bovine teeth are widely used in dentistry research (5,9), as preventive dentistry and Research Ethics Committees’ standards reduce the possibility of obtaining human teeth and hinder their use in in vitro studies. The need to reproduce the methodology in future research also supports this choice.

There is a difference between the wear level of diamond burs when applied to human teeth and when applied to bovine teeth because human tooth enamel has slightly higher resistance. Therefore, diamond bur wear may be greater in human teeth, and the results observed in this study must be carefully considered when extrapolating to clinical conditions. Nonetheless, the results of this study are consistent with previous research, in which gradual changes of the abrasive power of diamond burs on bovine teeth were observed (9).

The successive repetition of cavity preparations with the same diamond bur caused wear, as observed by the shape change and loss of diamond particles with consequent exposure of the metal rod. The same result was observed in the work of Simamoto-Junior et al. (2012) (10).

The advent of synthetic diamond made it possible to obtain diamond grains with different mechanical and physical properties. This diversity allows synthetic diamond to be used in a wide variety of abrasive applications (11). In the case of dentistry, diamond is widely used in the removal of dental tissue to accelerate surgical procedures (8).

The prolonged use of diamond burs lowers the wear efficiency of dental tissue and alters the shape of the instrument, which leads to additional difficulty in the structural cutting of the tooth. Wear on burs used in dental
preparations results in cutting difficulty, requiring the operator to exert greater pressure to compensate for the inefficiency of the worn bur, with a consequent increase in generated heat, which is medically unacceptable because the preservation of dental pulp is a predominant factor during cavity preparation (7).

Analysis of the burs with the scanning electron microscope revealed different degrees of wear and loss of diamond particles. Some particles that might not have been securely attached to the binding agent that fixed them to the rod were lost during use, reducing the tool's wear power. These observations are in agreement with previous studies (1,8,12,13) that confirmed that diamond rotary instruments may suffer loss of particles with successive use, damaging their cutting efficiency.

Unused burs have diamond particles with sharp angles across the surface, leaving no visible metal substrate. As the burs were used, wear and displacement of the diamond particles was observed, exposing craters corresponding to the locations where the diamonds were deposited. This result was also observed in the work of Abdul Aziz et al. (2011) (4).

The literature in general that addresses diamond bur wear has led to an understanding that in losing their roughness, worn burs also cause harmful effects to dental pulp and damage restorations (4,8,10,11). One such effect is a reduction in the roughness of the dental cavity, which decreases the ability to bond to dental tissue, as smoother surfaces react differently from rough surfaces and have different adhesive capacity (13).

Wear efficiency can vary according to several factors, including wear substrate, instrument brand, high-speed cooling and sterilisation process. With respect to the substrate, these instruments have better performance on enamel than on dentin, most likely because enamel is more mineralised than dentin (4) and results in less impregnation of the worn tissue on the diamond grains.

Rotary grinding instrument brands differ among themselves as to the degree of wear (3,10). Notably, the wear pattern of the tooth structure decreases proportionally to instrument usage (1,7).

The heterogeneous nature of the wear pattern among instruments of different manufacturers may be due to the manufacturing processes of the instruments. The size and density of diamond grains may lead to different wear values (10), and the agglutination process of the diamond particles onto the metal rod may cause greater or lesser resistance thereof. In this study, different manufacturers' instruments were not compared, only degree of wear. The choice of a single manufacturer meant that interference relating to the manufacturing process could be excluded.

The rotary instruments used in this study were the result of an electrolytic galvanic connection manufacturing process.
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The diamond burs contained medium-sized natural diamond particles (91-126 µm) attached to a stainless steel rod. It is difficult to ensure homogeneity in this manufacturing process, as the process of electrolessnickel plating onto a metal matrix does not confer the same qualities for all diamond burs, even if they belong to the same manufacturing lot. There are always differences relating to the average spacing between the grains and density of diamond abrasive grains, among other factors (11).

The size and density of the diamond forming the active bur of the instrument can also result in different amounts of wear. According to Galindo et al. (2004) (3) after a short period of use there is no difference in wear among fine, medium and coarse-grained instruments. However, when usage time is increased, there are differences between fine and medium grained instruments and medium and coarse-grained instruments. Coarse-grained diamond burs have better wear efficiency. The authors also observed that the lower the density of abrasive particles, the greater the deterioration of the burs.

Another factor that can affect instrument efficiency is the quality of irrigation during preparation. Water flow is extremely important in maintaining the effectiveness of the bur (14), as it removes debris and helps to maintain close contact between the active bur of the instrument and the tooth. If active bur impregnation occurs due to dental tissue fragments, restorative material and other products, such as blood, saliva and microorganisms, which tend to be compacted between the diamond particles, there will be reduced wear efficiency, requiring the operator to exert higher cutting pressure and therefore increasing frictional heat, which may also be harmful to the pulp.

In this research, the diamond burs were washed byultrasound, without a subsequent sterilisation procedure. The influence of sterilisation on the efficiency of rotary instruments remains unclear, and no consensus has been established thus far. The study by Bae et al. (2014) (15) demonstrates that sterilisation with ethylene oxide gas, chlorhexidine or autoclave has no negative effect on the cutting efficiency of diamond burs. However, other authors state that successive sterilisations of diamond burs can aggravate their wear (10). The process of autoclaving, which consists of subjecting the diamond bur to a temperature of 120° C for 20 minutes in an atmosphere saturated with water vapour, causes greater thermal expansion of the nickel than of the diamond grains. Thus, when the burs are subjected to a temperature increase, a passage opens between the diamond grain and the nickel anchor, allowing the infiltration of water vapour. Upon cooling, the vapour condenses in the region between the diamond grain and the nickel layer, causing corrosion of the latter and thus reducing the retention capacity of the diamond grains. This wear mechanism of diamond burs subjected to sterilisation by
autoclaving is clearly noted in the studies of Sung et al. (2013) (16), Borges et al. (1999) (17) and Simamoto-Júnior et al. (2012) (10). Wear can be observed as the diamond burs are repeatedly subjected to chemical sterilisation in a solution of 1% glutaraldehyde. Glutaraldehyde becomes a more powerful sterilising agent as its concentration in the solution increases. However, as the concentration increases, its corrosive action also increases which is responsible for the decreased wear ability of burs subjected to this type of chemical sterilisation (10).

Diamond burs subjected to an oven sterilisation process have better cutting performance than diamond burs sterilised by autoclave or glutaraldehyde. In Simamoto-Júnior et al.’s study (2012) (10), using glutaraldehyde and cleaning with ultrasound also resulted in a major loss of diamond. That is, oven sterilisation better preserved the diamond bur's ability to remove material. Oven sterilisation is thus the best process for diamond burs, as it has a less deleterious effect on their cutting ability. Furthermore, in this study, after the first and up to the second sterilisation, it facilitated an improved cutting performance in relation to the control group.

Diamond burs subjected to a sterilisation process in a dry environment (170° C/60 min) and cooled to ambient temperature suffer hardening of the nickel layer present on the metal matrix of such instruments. Furthermore, when used, a concentration of stress occurs between the diamond grains and metal matrix, producing separation of the coalescence. Thus, the instrument loses its diamond grains and becomes ineffective (18). The process of anchoring the diamond to the metal rod is achieved using electroless nickel plating. As nickel consists of monatomic crystals, when heated for a long time and cooled to room temperature, it undergoes an atomic adaptation in which its atoms draw together, increasing its hardness. This process produces better anchorage for the diamond grains, which remain trapped on the rod, even during tangential cutting forces greater than those supported by diamonds in diamond burs not subjected to this thermal process. However, the increase in the hardness of the nickel layer causes stress concentration in regions in contact with the diamond grains. Sterilisation methods and repeated use structurally alter cutting instruments. Therefore, the use of a protocol that involves a combination of methods that promote the cleanliness and effectiveness of diamond burs would be ideal (10).

The option of using disposable diamond burs would be a way to eliminate the need for sterilisation of the instrument and to avoid harmful effects to the dentin-pulp complex caused by an instrument that has sustained wears through repeated use.

The cost of the manufacturing process of disposable burs is approximately the same as that of the manufacturing process of diamond burs used currently. However, quality control can be less strict in the case
of disposable burs, as they are typically less demanded (19).
Dental professionals should be informed of the whole arsenal that is at their disposal in dental surgery, so it is important to know the manufacturing process, durability, technique, substrate interference and possible changes that the instrument might suffer due to the sterilisation process that is required for repeated use.

CONCLUSION
Within the constraints of this study, SEM revealed that the analysed burs showed different and increasing degrees of wear and loss of diamond particles as they were subjected to a larger number of cavity preparations, with significant differences between all groups evaluated.
The use of diamond burs after the fifth preparation is questionable. After the tenth cavity preparation, the diamond burs showed severe wear and loss of diamond particles with exposure of large areas of the metal rod. This number of reuses must therefore be avoided.

Conflicts of interest
The authors declare no financial support and no potential conflicts of interest with respect to the authorship and/or the publication of this article including any financial, personal or other relationships with other people or organizations within three years of beginning the submitted work that could inappropriately influence or be perceived to influence this work.

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