Cutting Efficiency of Different Diamond Burs after Repeated Cuts and Sterilization Cycles in Autoclave

Abstract

Context: The aim was to evaluate the cutting efficiency of different diamond burs after successive cuts and repeated sterilization in an autoclave. The morphology and grit sizes were analyzed and correlated to cutting efficiency. Materials and Methods: Ten medium-grit diamond burs of five different manufacturers were investigated (KG, KG Sorensen; TH, Tri-Hawk; KM, Komet; HC, Heico; and FD, Frank Dental). Changes in the cutting efficiency of diamond burs on composite resin blocks were measured after four repeated cuts and after five sterilization cycles. Grit sizes were analyzed by scanning electron microscopy (SEM) and correlated to cutting efficiency. The data were statistically analyzed using 3-way ANOVA and Tukey’s test (α = 0.05). Results: Significant differences were observed for diamond burs (P < 0.0001) and condition (P < 0.0001). FD presented the lowest mean cut time (21.88s), followed by KM (36.08s), TH (40.18s), HC (41.65s), and KG (42.23s) had the highest cut times. The number of cuts was not statistically significant. New burs had a significantly shorter cutting time (33.38s) when compared with the ones after sterilization cycles (39.55s). A moderate to strong positive correlation was found between diamond size and cutting time (Pearson’s coefficient of 0.77). Conclusion: All diamond burs demonstrated lower cutting efficiency after repeated autoclaving. Cutting efficiency did not decrease as the number of cuts increased.

Keywords: Autoclave, cutting efficiency, diamond bur, disinfection

Introduction

Diamond burs are usually the rotary instruments of choice for many restorative procedures, such as cavity preparation for direct and indirect restorations, enameloplasty, grinding and polishing of definitive restorations, and also removing defective restorations before replacement. For the last 20 years, composite resin restorations are the most used in clinical practice. Besides good clinical longevity (success rate of 63% over 30 years, with an annual failure rate of 1.1%),[1] a significant number of these restorations need regular replacement because of problems related to marginal integrity, staining, wear, secondary caries, and post-operative sensitivity.

To replace defective restorations, it is necessary to use diamond rotary instruments with safe, fast, and efficient cutting, avoiding damage to dental structure and increasing pulp temperature.[2] Regarding the characteristics of diamond burs, cutting efficiency is one of the most important properties to consider when selecting a diamond bur.[3] In Dentistry, the cutting efficiency has been described as the amount of substrate (tooth or dental material) that can be removed within an indicated period. Consequently, longer cutting time simply reduced cutting efficiency.[4]

The cutting rate of diamond burs is generally affected by several factors, including grit size,[5] coolant flow,[6] load applied by the operator, design, tooth structure/restorative material being removed,[2] repeated use,[3,4,7] and sterilization.[5,7] Some studies demonstrated a reduction in cutting efficiency after repeated use of diamond burs. In general, as the number of cuts increases, the cutting efficiency decreases. In addition, this decrease is larger after the first cut.[5,8] Many aspects may be related to this fact, such as, abrasion and/or the deposition of substrate remnants[4] and loss of diamond grains and matrix material.[8]

During clinical use, rotary instruments are frequently exposed to saliva, blood, and oral tissues. To prevent the occurrence of cross-contamination, these materials...
should be correctly washed, disinfected, and sterilized. Literature reports that after repeated cycles of sterilization, the longevity or cutting efficiency of the diamond tips may be impaired.\textsuperscript{[10,7,9]} There is no clear consensus in the literature regarding the influence of sterilization methods on the cutting efficiency of diamond rotary instruments.\textsuperscript{[2]}

Thus, the purpose of this study was to evaluate the influence of successive cuts and repeated sterilization in autoclave on the cutting efficiency of different diamond rotary instruments. In addition, the morphology and grit sizes were analyzed by SEM and correlated to cutting efficiency. The tested hypotheses were that (i) there would be significant differences in the cutting efficiency of the tested diamond burs; and (ii) the cutting efficiency of the burs would be affected by repeated cuts sterilization cycles in autoclave.

Materials and Methods

This study investigated medium-grit round end tapered diamond burs of five different manufacturers and available in the Brazilian market: KG (3195, KG Sorensen, Barueri, SP, Brazil); TH (166-016C, Tri Hawk Inc., Morrisburg Ontario, Canada); KM (859.314.018, Komet, Brasseler, Germany); HC (859.314.010, Heico, Steinach, Switzerland); and FD (D.859.314.010.FG, Frank Dental, Gmund/Tegernsee, Germany). The cutting surfaces of the diamond burs were 10-mm long, and the instruments were tapered, with a diameter of 1 mm in the thickest area of the cutting surface.

Cutting efficiency was determined using a high-speed air-turbine (Gnatus Equipamentos Médico-Odontológicos, São Paulo SP, Brazil) mounted on a device that allowed the application of a constant load of 300 g to perform the standardized cuts. The handpiece was operated at 150,000 rpm under a coolant water spray of 20 mL/min. A composite resin (NT Premium, Coltene, Altstätten, Switzerland) cylinder with 7.5 mm in diameter was used as cutting substrate. Composite resin cylinders were produced using split Teflon moulds, with 7.5 mm in diameter and 10 mm in thickness. An incremental technique was used, and the 2 mm increments were light-cured with a LED photo-curing unit (Radii-cal, SDI, Bayswater, Australia) with 1200 mW/cm\(^2\) irradiance for 40 s. The mechanical properties of this resin composite are Knoop hardness of 62.6 kg/mm\(^2\) and an elastic modulus of 25.5 GPa.\textsuperscript{[30]}

Cutting efficiency was evaluated by making five standardized, consecutive cuts with each diamond bur on the resin composite substrate (n = 10). The time needed to cut the 7.5 mm of resin composite was determined and compared between groups.

Another 10 new diamond burs of each manufacturer were subjected to five disinfection cycles in autoclave, to simulate repeated use in dental practice. Autoclaving disinfection was performed at 126–129°C (1.7 to 1.8 kgf/cm\(^2\)) for 15 min using a pressure steam sterilizer (Cristofoli, Campo Mourão, PR, Brazil). After the five disinfection cycles in autoclave, cutting efficiency was determined again.

Scanning electron microscopy images (JSM-6010LA, Jeol, Tokyo, Japan) were obtained from the diamond burs in the following conditions: new burs, after the five consecutive cuts and after disinfection cycles in autoclave. Characteristics related to diamond loss and wear and morphology were observed in each condition. In addition, the average size of the diamonds was determined by measuring their long axes (two burs of each manufacturer and five diamond particles in each bur). Data were also obtained for the semi-quantitative chemical analysis of the diamond and metal matrix, using an energy dispersion spectrometer (EDS).

For each diamond bur, the data for cutting efficiency were statistically analyzed using two-way ANOVA (number of cuts and condition) and Tukey’s test with a significance level of 0.05. The correlation between diamond grain size and cutting time was performed using Pearson’s coefficient.

Results

The results for cutting efficiency are shown in Table 1. For KG, the results of the statistical analysis did not show significant differences for number of cuts (P = 0.3606), condition (P = 0.3869), and for the double interaction number of cuts * condition (P = 0.9066). For the number of cuts, the average times for the five sequential cuts were cut 1 (39.54 ± 8.29 s), cut 2 (39.86 ± 6.60 s), cut 3 (43.29 ± 7.74 s), cut 4 (43.13 ± 6.57 s), and cut 5 (45.31 ± 5.97 s). For the diamond bur condition, new and autoclaved burs presented statistically similar average cutting time (41.32 ± 5.28 s and 43.14 ± 8.64 s, respectively).

For TH, the results of the statistical analysis did not show significant differences for number of cuts (P = 0.6821) and for the double interaction number of cuts * condition (P = 0.9238). Condition showed significant differences (P < 0.0001). For the number of cuts, the average times for the five sequential cuts were cut 1 (38.51 ± 7.21 s), cut 2 (39.18 ± 7.41 s), cut 3 (40.48 ± 6.94 s), cut 4 (41.09 ± 6.10 s), and cut 5 (41.62 ± 4.05 s). For the diamond bur condition, new burs had a significantly shorter average cutting time (36.49 ± 5.05 s) than the ones subjected to autoclave cycles (43.87 ± 5.22 s).

For KM, the results of the statistical analysis did not show significant differences for number of cuts (P = 0.3175) and for the double interaction number of cuts * condition (P = 0.9435). Condition showed significant differences (P = 0.0003). For the number of cuts, the average times for the five sequential cuts were cut 1 (35.82 ± 5.48 s), cut 2 (36.00 ± 4.41 s), cut 3 (34.28 ± 4.06 s), cut 4 (35.93 ± 4.99 s), and cut 5 (38.36 ± 4.27 s). For the diamond bur condition,
autoclaved burs had a significantly shorter average cutting time (33.75 ± 4.70 s) than the new burs (38.40 ± 3.33 s).

For HC, the results of the statistical analysis did not show significant differences for number of cuts \((P = 0.8337)\) and for the double interaction number of cuts * condition \((P = 0.8525)\). Condition showed significant differences \((P < 0.0001)\). For the number of cuts, the average times for the five sequential cuts were cut 1 \((39.85 ± 5.20 \text{ s})\), cut 2 \((40.82 ± 4.19 \text{ s})\), cut 3 \((42.48 ± 3.85 \text{ s})\), cut 4 \((43.20 ± 4.73 \text{ s})\), and cut 5 \((41.88 ± 4.05 \text{ s})\). For the diamond bur condition, new burs had a significantly shorter average cutting time \((28.13 ± 2.65 \text{ s})\) than the ones subjected to autoclave cycles \((52.46 ± 7.20 \text{ s})\).

For FD, the results of the statistical analysis showed significant differences for number of cuts \((P = 0.018838)\) and condition \((P < 0.001)\). The double interaction number of cuts * condition was not significant \((P = 0.229829)\). For the number of cuts, the average times for the five sequential cuts were cut 1 \((22.35 ± 3.96 \text{ s})\), cut 2 \((19.70 ± 3.11 \text{ s})\), cut 3 \((21.31 ± 2.73 \text{ s})\), cut 4 \((23.51 ± 5.01 \text{ s})\), and cut 5 \((22.53 ± 4.10 \text{ s})\). For the diamond bur condition, new burs had a significantly shorter average cutting time \((18.55 ± 2.25 \text{ s})\) than the ones subjected to autoclave cycles \((24.54 ± 2.51 \text{ s})\).

SEM images for the new diamond burs showed that all burs had a relatively homogeneous distribution of diamonds in the head. KG showed diamond loss in some places, whereas TH showed the presence of non-diamond particles, suggestive of zirconia, according to EDS analysis. FD and HC showed the presence of defects in the metal matrix and clusters of diamonds [Figures 1 and 2].

Regarding the average size of diamonds, there was variation between the different burs analyzed, with values between 77.56 and 168.09 \(\mu\text{m}\). The mean, minimum, and maximum values for diamond size are shown in Table 2. A moderate to strong positive correlation was found between diamond size and cutting time, so that the higher the diamond granulation, the longer the cutting time (Pearson’s correlation coefficient of 0.77) [Figure 3].

Semi-quantitative EDS analysis of diamond tips showed that all diamonds, as expected, had a carbon composition, but at TH bur, diamonds were found that showed traces of other elements, such as Al and Ni. Regarding the metal matrix, only KM bur showed homogeneity in relation to the assessment points, with composition 100% Ni. In the metal matrix of the other burs, other elements were found, such as Cr, O, P, Al, and Fe [Table 3].

Regarding the burs after the cuts and after the autoclave cycles, in comparison with the new ones, SEM images showed no significant differences, indicating little loss of diamonds and wear. In some images, the deposition of the cutting substrate adhered among the diamond grains could also be observed.

**Discussion**

According to the results, the hypothesis that there would be differences among the diamond burs tested regarding their cutting efficiency was accepted. FD presented the lowest mean cut time, whereas KG had the highest mean cut time. The SEM and EDS analysis showed different mean diamond sizes and compositions of the metal matrices of the burs. This could be one of the possible explanations for the differences in cutting efficiency. TH presented slightly different characteristics that may have influenced its cutting efficiency. The SEM analysis showed the presence of particles suggestive of zirconia. In addition, it is important to note that TH presented the highest mean diamond grain sizes. The positive correlation between diamond grain size
Table 1: Mean and standard deviation for the cutting times of the diamond burs tested under different conditions*

| Diamond bur | Condition                  | Cut #1       | Cut #2       | Cut #3       | Cut #4       | Cut #5       |
|-------------|----------------------------|--------------|--------------|--------------|--------------|--------------|
| KG          | New                        | 37.17±3.93*  | 38.10±3.62*  | 42.65±3.78*  | 42.77±5.17*  | 45.89±3.46*  |
|             | After autoclave cycles     | 41.91±9.86*  | 41.62±7.69*  | 43.94±9.63*  | 43.49±7.12*  | 44.72±7.18*  |
| TH          | New                        | 33.76±4.35*  | 35.00±4.78*  | 37.60±5.09*  | 37.41±5.55*  | 38.69±2.7*   |
|             | After autoclave cycles     | 43.17±5.42*  | 43.38±6.41*  | 43.37±6.66*  | 44.78±3.00*  | 44.54±2.24*  |
| KM          | New                        | 38.02±4.41ab | 38.27±3.86ab | 37.48±1.43ab | 37.53±2.32ab | 40.69±1.22ab |
|             | After autoclave cycles     | 33.62±4.98ab | 33.73±3.13ab | 31.07±2.60ab | 34.33±5.85ab | 36.02±4.17ab |
| HC          | New                        | 27.82±1.37a  | 28.43±3.48a  | 27.40±2.12a  | 28.81±3.78a  | 28.21±1.50a  |
|             | After autoclave cycles     | 49.47±9.99ab | 50.73±6.69b  | 54.55±7.30b  | 54.72±4.01b  | 52.83±3.66b  |
| FD          | New                        | 18.90±3.05ab | 17.20±2.47a  | 18.93±1.09ab | 18.64±2.13ab | 19.08±0.82ab |
|             | After autoclave cycles     | 25.11±0.72cd | 21.70±1.27abc| 23.22±1.67bcd| 27.40±1.54d  | 25.29±3.03cd |

*Letters (a, b, c, d) are used to indicate significance levels (P < 0.05). For each diamond bur, when the same letter is used, the difference between the means is not statistically significant. If two values have similar letters, they are significantly different.

Figure 2: SEM micrographs indicate some particularities from the diamond burs tested: KG demonstrates areas with diamond loss; TH shows particles that may not be diamond, EDS indicates the presence of zirconia at these sites; HC also demonstrates some areas with defects and diamond clusters and cutting time suggested that, as the size of the diamond increased, the cutting time of the composite resin also increased, indicating that the cutting efficiency decreased. These results are in disagreement with other studies, which reported that cutting efficiency increased with the size of diamond grains.[5,11-13]

Diamond burs are manufactured by galvanic deposition of diamond powder onto metal, however, there are some inherent limitations to this technology, because the diamonds can be dislodged, as demonstrated in Figure 2, negatively influencing the cutting efficiency of the rotary instrument. Moreover, the heterogeneity in the shape of the diamond particles makes the surface irregular, favoring the retention of dental debris, microorganisms, and materials, and making the burs more difficult to sterilize and less durable.[4] This study investigated the cutting efficiency of diamond burs on a composite resin substrate. However, it is important to highlight that, besides diamond burs, tungsten carbide fluted burs are also suitable for bulk removal of composite resin. Tungsten carbide burs are also commonly used to remove composite remnants after bracket debonding, excess-filled composite, and refine anatomical contouring.

The hypothesis that there would be differences between the first and fifth cuts of each diamond bur tested was rejected. The present study performed five cuts with each rotary instrument, and the number of consecutive cuts varies greatly in the literature, from three[5] to twenty[8] cuts per bur, with varied lengths, duration and on different substrates. Previous studies reported a reduction in the cutting efficiency of diamond burs, as the number of cuts is increased.[3,8] However, it is important to point out that these studies used ceramic blocks as cutting substrates, whereas the present study used composite resin. In the present study, nanohybrid composite resin was used as cutting material, to simulate one of the most common clinical situations, i.e., the replacement of defective composite resin restorations. Therefore, it is important to understand the cutting efficiency of different diamond burs on composite resin substrates. Glass-ceramics are the most common cutting substrate used in studies evaluating the cutting efficiency of diamond burs[5,7,8,14] because their mechanical properties, such as hardness and elastic modulus are similar to those of enamel.[3] Cast metals[15] and zirconia[11,12] are also used as cutting specimens.

According to the results, the hypothesis that there would be differences in cutting efficiency regarding the condition of the diamond burs (new and after sterilization cycles in autoclave) was accepted. The present study found that autoclaving affected the cutting efficiency of the diamond burs tested. Bae et al.[3] reported that the cutting efficiency was not influenced...
by repeated disinfection. However, Gureckis et al.\textsuperscript{[16]} reported that the cutting efficiency of diamond burs was not affected after 10 successive disinfection cycles, including autoclaving. However, the cutting efficiency tended to decrease with the number of disinfection procedures.\textsuperscript{[16]}

This study evaluated the influence of repeated cuts and sterilization cycles in autoclave on the cutting efficiency of different dental diamond burs, and the results obtained could be used to help clinicians when selecting their diamond rotary instruments for clinical practice. However, future studies are necessary to better understand the processes involved in the wear and cutting efficiency of different rotary instruments.

**Conclusions**

It can be concluded that the cutting efficiency of the tested diamond burs was influenced by brand and condition. All diamond burs demonstrated lower cutting efficiency after repeated autoclaving. Cutting efficiency did not decrease as the number of cuts increased, regardless of the decrease bur used in composite resin substrates. A positive correlation was found between diamond size and cutting time.

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Nil.

**Conflicts of interest**

There are no conflicts of interest.

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**Table 2: Mean, minimum, and maximum values for diamond sizes (two burs of each manufacturer and five diamond particles in each bur)**

| Diamond bur | Diamond size (in µm) | Mean   | Minimum | Maximum |
|-------------|----------------------|--------|---------|---------|
| KG          |                      | 105.42 | 90.43   | 117.09  |
| TH          |                      | 168.09 | 102.42  | 240.53  |
| KM          |                      | 116.17 | 84.34   | 136.46  |
| HC          |                      | 96.11  | 81.68   | 119.81  |
| FD          |                      | 77.56  | 55.62   | 93.13   |

**Table 3: EDS semi-quantitative chemical analysis of the diamond particles and metal matrix**

| Diamond bur | Metal matrix | Diamond     |
|-------------|--------------|-------------|
| KG          | Ni (70%)     | C (100%)    |
|             | Cr (27%)     |             |
|             | O (3%)       |             |
| TH          | Ni (89 to 99%) | Traces of Al and Ni |
|             | P (0.85 to 8.99%) |           |
|             | Al (0.48 to 1.99%) |       |
| KM          | Ni (100%)    | C (100%)    |
| HC          | Ni (99.48 to 99.84%) | C (100%)   |
|             | Al (0.16 to 0.52%) |       |
| FD          | Ni (95.76 to 100%) | C (100%)   |
|             | Fe (4.24%)   |             |