Influence of sterilization process on cutting effectiveness and durability of ultrasonic tips

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ABSTRACT

Objectives: The aim was to evaluate influence of different sterilization methods on cutting effectiveness and durability of cylindrical ultrasonic burs compared with conventional cylindrical diamond-coated burs. Material and Methods: Fifteen conventional cylindrical diamond-coated (1092) (KG Sorensen) coupled to a high-speed turbine, and fifteen cylindrical ultrasonic (8,2137) (CVDentus®) burs coupled to an ultrasound-handpiece were used to perform standardized cavity preparations in healthy bovine tooth fragments, cleaned with rubber cup, pumice stone and water. After every 10 preparations, burs were sterilized 9 times in autoclave (SA), oven (SO), or cleaned with brush, soap and water (C). Fragments were weighed and microphotographs of burs were taken at the beginning and end of experiment. Another 9 conventional diamond-coated and 9 CVD burs underwent the same sterilization cycles in autoclave (SAC), oven (SOC) or washed with soap and water (CC) however, without being used for making cavity preparations, serving as control. Descriptive analyses were made of the values found by weighing and microphotography scores. Results: Statistically significant differences (Paired Student’s-t test) were observed among burs after sterilization (p = 0.0001). SO and SA did not influence cutting effectiveness and durability of ultrasonic and conventional diamond-coated burs. The microphotographs showed morphological differences between the burs used for preparation and the control. Conclusion: Sterilization by oven and autoclave did not influence cutting effectiveness and durability of ultrasonic and conventional diamond-coated burs.

RESUMO

Objetivo: O objetivo foi avaliar a influência de diferentes métodos de esterilização na efetividade de corte e durabilidade de pontas ultra-sônicas cilíndricas comparadas com pontas diamantadas cilíndricas convencionais. Material e Métodos: Quinze pontas diamantadas cilíndricas (1092) (KG Sorensen) acopladas a um motor de de alta rotação, e quinze pontas ultrassonicas cilíndricas (8,2137) (CVDentus®) acopladas a um ultra-som foram utilizadas para realizar preparos cavitários padronizados em fragmentos de dentes bovinos higidos, limpos com taça de borracha, pedra-pomes e água. Após cada um dos 10 preparos, as pontas foram 9 vezes esterilizadas em autoclave (SA), estufa (SO), ou limpas com escova, sabão e água (C). Os fragmentos foram pesados e microfotografias das pontas foram tomadas no início e no final do experimento. Outras 9 pontas de diamante CVD e 9 convencionais foram submetidos aos mesmos ciclos de esterilização em autoclave (SAC), forno (SOC) ou lavado com água e sabão (CC) no entanto, sem serem usados para fazer preparos cavitários, servindo como controle. Realizou-se análise descritiva dos valores encontrados na pesagem e dos scores das microfotografias. Resultados: Diferenças estatisticamente significativas (teste t do Student pareado) foram observadas entre as pontas após a esterilização (p = 0,0001). SO e SA não influenciaram na efetividade de corte e durabilidade das pontas diamantadas ultra-sônicas e convencionais. As microfotografias mostraram diferenças morfológicas entre as pontas utilizadas para os preparos e o controle. Conclusão: As esterilizações por autoclave e estufa não influenciaram a efetividade de corte e durabilidade das pontas diamantadas.
durability of CVD and conventional diamond-coated burs. Conventional diamond-coated burs presented greater structural alterations after performing cavity preparations and cleaning/sterilization procedures, irrespective of the process used.

**KEYWORDS**
CVDentus; Sterilization; Dental instruments; Infection control.

**INTRODUCTION**

During cavity preparation, diamond-coated burs are frequently exposed to saliva, blood and oral cavity tissues. In order to prevent the occurrence of cross contamination between patients and professionals, correct washing, disinfection and sterilization of materials must be performed [1-7]. Therefore, the specific substances and methods used during these procedures may interfere in the durability and effectiveness of the burs [8-12].

Conventional diamond-coated burs are manufactured by galvanic deposition of diamond powder onto metal rods, however, there are some limitations inherent to this technology, because the diamonds are easily dislodged, negatively influencing their cutting effectiveness. Moreover, the heterogeneity in the shape of the diamond granules makes the surface irregular, favoring the retention of dental debris, microorganisms and materials, and making the burs more difficult to sterilize and less durable [13-15].

In the mid-1990s, the National Institute for Space Research (INPE) developed an artificial diamond, produced by the process of chemical steam deposition adhered to angulated molybdenum rods, living rise to the CVDentus burs, which are used coupled to an ultrasound handpiece [16-20].

CVDentus burs have been used for different purposes, primarily for minimally invasive cavity preparation, as they have the characteristic of very conservative tissue removal [21-25]. They are also helpful when used in endodontic treatments [26], and for the removal of excess material from gingival margins without harming the periodontal tissue [27]. In addition, these burs present surface uniformity and completely coalescent edges, which provide a better finishing quality and greater facility in cavity cleaning, when compared with conventional diamond-coated burs [19].

The different characteristics of methods used for sterilization define their use: sterilization in an oven requires the material to remain at 170 °C for 1 h or at 160 °C for 2 h. The dry heat produced by the oven promotes sterilization by bacterial dehydration. The time spent to complete this cycle and the number of variables that interfere in it contributed to limiting its use [28].

Autoclaving promotes sterilization by the action of steam from water superheated to 121 °C or 134 °C and maintained under pressure of 1 or 2 atm, with a dwell time of between 30 and 15 min, respectively. With the increase in heat and humidity, bacteria are denatured, and it is therefore considered more practical and effective than the oven [11,29,30].

The morphological characteristics of diamond-coated and ultrasonic burs, such as surface shape, may make the cleaning and sterilization process difficult or easy, and it is suggested that the behavior or ultrasonic burs under the action of these different sterilization processes.
methods may also differ. Therefore, the aim of the present study was to evaluate the influence of different sterilization methods on the cutting effectiveness and durability of cylindrical ultrasonic burs in comparison with conventional cylindrical diamond-coated burs.

**MATERIAL AND METHODS**

In this study, 15 conventional cylindrical diamond-coated burs (1092) (KG Sorensen, Alphaville-SP, Brazil) coupled to a high-speed turbine, and 15 cylindrical ultrasonic burs (8.2137) (CVDentus® Clorovale Diamantes, São José dos Campos-SP, Brazil) coupled to an ultrasound handpiece were used. These 30 burs were divided into 6 groups, composed of five burs of each type, which were used to perform cavity preparations. Three hundred healthy bovine anterior teeth, with the absence of cracks and structural defects were selected. The teeth were cleaned with a rubber cup, pumice stone and water. The mesial and distal portions of the roots were removed, by using a diamond-coated disc in a precision cutting machine ISOMET™ 1000 (Buehler®, Lake Bluff, II, USA), and the specimens were embedded in PVC tubes (1 cm high by 2 cm in diameter) with condensation silicone (Zetalabor® - Zhermack, Italy).

These test specimens were fitted to a standardizing machine [21] that allowed each preparation in the enamel surface to be performed in 120 s, with a run distance of 3.5 mm, speed 5.3 mm/s and pressure of 0.12 N.

After each preparation the burs were submitted to cleaning with a brush, soap and water (C), sterilization in an autoclave (SA) at 134 ºC for 4 min or sterilized in an oven (SO) at 170 ºC for 1 h, as recommended by the Brazilian Ministry of Health.

The cavity preparation and cleaning or sterilization sequence was repeated until each tip had completed 1200 s of use in ten test specimens and nine cleaning or sterilization cycles (Table 1).

To evaluate the cutting effectiveness of each tip, specimens were weighed before and after the preparations, using a precision scale Sartorius BL 210S.

To evaluate the effect of sterilization on this effectiveness, the differences in weights obtained before and after the cavity preparation and cleaning or sterilization cycles were calculated. This difference in weight among the blocks of test specimens showed the quantity of tissue removed.

In addition, the burs were observed under a stereoscopic microscope and digital images were obtained by using the Leika Qwin (100x

### Table 1 - Tip specifications, quantity of tooth specimens used, time of performing cavity preparations and number of cleaning/sterilization cycles

|                | Conventional diamond-coated tip (n) | CVDentus tip (n) | Number of test specimens used | Total preparation time | Cleaning/Sterilization cycles |
|----------------|-------------------------------------|-----------------|-------------------------------|------------------------|-------------------------------|
| SA             | 5                                   | 5               | 100                           | 1200"                  | 9                             |
| SO             | 5                                   | 5               | 100                           | 1200"                  | 9                             |
| C              | 5                                   | 5               | 100                           | 1200"                  | 9                             |
| SAC            | 5                                   | 5               | 0                             | 0                      | 9                             |
| SOC            | 5                                   | 5               | 0                             | 0                      | 9                             |
| CC             | 5                                   | 5               | 0                             | 0                      | 9                             |

SA: Sterilization in autoclave
SAC: Sterilization in autoclave without cavity preparation
SO: Sterilization in oven
SOC: Sterilization in oven without cavity preparation
C: Cleaning with brush, water and soap
CC: Cleaning with brush, water and soap without cavity preparation
magnification) program, before beginning the preparations and after the ninth cleaning or sterilization cycles. These digital images were analyzed and classified in accordance with the adapted scores:

- Score 0: absence of tip wear and loss of part of the diamond structure
- Score 1: alteration in shape of the tip structure
- Score 2: Loss of part of the diamond structure
- Score 3: Alteration in shape and loss of part of the diamond structure
- Score 4: Alteration in shape and loss of diamond structure
- Score 5: loss of diamond structure with complete exposure of metal

As control of durability, another nine ultrasonic burs and nine conventional diamond-coated burs were brushed with soap and water (CC), sterilized in an autoclave (SAC) or oven (SOC). These burs were not used for cavity preparations, and were analyzed by means of microphotographs, with the purpose of comparing them with the burs used to perform cavity preparations.

For comparison among the different groups, the paired t-test was used. The durability data were descriptively analyzed.

### RESULTS

The burs used in Groups (CC), (SAC) and (SOC) showed no difference whatever in shape and structure.

The weight loss of the specimens after cavity preparations is shown in Table 2.

The values found showed normal distribution. Statistically significant differences (p < 0.05) were observed when the conventional burs were compared with the ultrasonic burs after the three methods of sterilization (p = 0.0001). In addition, sterilization in the oven also significantly influenced (p = 0.0003) the cutting effectiveness of the conventional diamond-coated burs when compared with the control group and the method of sterilization in autoclave.

The results of the stereoscopic microscopy analysis of the burs are presented in Table 3 and illustrated in Figure 1.

**Table 2** - Mean of difference in weight (grams) of test specimens before and after cavity preparations

| Burs            | CVDentus® (CVD) | Conventional Diamond-coated (DC) |
|-----------------|-----------------|----------------------------------|
| Groups          | SA              | S0                               |
|                 | C               | SA                               |
| Means           | 0.0151          | 0.0123                           |
|                 | 0.0140          | 0.0637                           |
|                 | 0.0376          | 0.0521                           |

SA: Sterilization in Autoclave
S0: Sterilization in oven
C: Cleaning

**Table 3** - Descriptive analysis of digital images of ultrasonic burs (CVD) and conventional diamond-coated burs (DC) before (b) and after (a) cavity preparations

|             | Sterilization in Autoclave (SA) | Sterilization in Oven (SO) | Cleaning with brush Scores (C) |
|-------------|---------------------------------|---------------------------|-------------------------------|
| Scores      | CVDb                            | CVDa                      | DCb                          |
|             | DCa                            | CVDb                      | CVDa                         |
|             | DCb                            | DCa                       | DCb                          |
|             | DCa                            | CVDb                      | CVDa                         |
|             |                                | DCb                       | DCa                          |
| 0           | 5                               | 2                         | 5                             |
| 1           | 2                               | 3                         | 5                             |
| 2           | 3                               | 1                         | 5                             |
| 3           | 1                               | 5                         | 4                             |
| 4           |                                 |                            |                               |
| 5           |                                 |                            |                               |
| Total       | 5                               | 5                         | 5                             |

SA: Sterilization in Autoclave
S0: Sterilization in oven
C: Cleaning
DISCUSSION

The conventional diamond-coated burs have rods composed of a resistant metal, such as steel or stainless steel with small gaps or depressions in which the diamond grit is lodged. The size and shape of these gaps determine the size and shape of the burs, and the natural or synthetic diamond grit may be bonded to the gaps in the metal in diverse ways, among them the methods of electrolytic co-deposition, welding, agglomeration or the use of adhesives, and these chips may become dislodged with use [31].

The ultrasonic burs of the CVDentus system have a low coefficient of friction and controlled granulometry, making them biologically compatible, as they do not leave metal residues in the teeth and do not aggregate dentinal residues [32]. They provide a hybrid layer similar to that of the conventional diamond-coated and carbide burs [33]. Furthermore, because they are composed of a single diamond stone, with thousands of microscopic edges, suggesting a more lasting durability than the conventional burs.

The mechanism of sterilization in autoclave has been suggested to interfere in the durability and cutting effectiveness of instruments used in the dental office, due to corrosion. The results of descriptive analysis of the digital images (Table 3) showed that all the conventional diamond-coated burs sterilized in autoclave underwent changes in shape and loss of part of the diamond structure (Score 3). Authors such as Siegel et al. [14] and Savage et al. [30], justified the possible corrosion caused as being due to the humid head. Nevertheless, our results showed that the test specimens prepared with the conventional diamond-coated burs, sterilized in autoclave (SA) (Table 2), presented a higher mean weight loss value, suggesting greater cutting effectiveness when compared with the burs sterilized in the oven. It may be suggested that this corrosion caused by the humid head was responsible for the loss of diamond grains from the conventional diamond-coated burs.

Furthermore, it has been suggested that sterilization by dry heat did not diminish the cutting capacity of the rotary instruments, when compared with any other type of sterilization. According to Miller et al. [11] and Cooley et al. [34] the dry environment that promoted bacterial dehydration, indirectly maintained the integrity of the stainless steel instruments, preventing oxidation and corrosion and could even have improved some of the properties, such as fracture strength in different types of burs. In our study, the specimens that were prepared with conventional diamond-coated burs and
sterilized in the oven had a lower weight loss after the preparations than the burs in the other groups (Table 2). However, in the analysis of the photomicrographs, the burs presented only change in shape, without loss of diamonds (Table 3 - Score 1).

Other rotary instruments have also been studied with regard to the influence of sterilization, Fais et al. [10] evaluated the influence of different types of sterilization on the cutting effectiveness of carbide burs and verified that the oven was the method that least affected the cutting capacity of these burs. Whereas, in 2011, Spranley et al. [35], in a similar study concluded that up to 10 cycles of autoclaving did not significantly affect the cutting efficacy in cavity preparation.

We may therefore suggest that performing the cavity preparations contributed to the wear in the majority of the conventional diamond-coated burs, which presented changes in shape and loss of part of the diamond structure, as shown in the photomicrographs (Table 3). These findings are in agreement with Siegel and Fraunhofter [14], who suggested the low durability of the burs was due to the type of adhesion of the diamond grit to the metal rod. These alterations were not observed to a great extent in the photomicrographs of the ultrasonic burs used for performing cavity preparations, and submitted to the sterilization processes in our study (Table 3) in agreement with the findings of Predebon et al. [17].

The ultrasonic burs provided lower mean weight loss values when compared with the conventional diamond-coated burs, suggesting lower cutting effectiveness, i.e. less wear of dental structure, irrespective of the sterilization/cleaning process used. Vanderlei et al. [36], in their study, reported that the CVDentus burs needed 4 times more time to perform the same preparation as needed when using the conventional diamond-coated tip, also demonstrating its lower cutting capacity.

Predebon et al. [17] observed that the cavity preparations performed with the ultrasonic burs were more conservative than those performed with the conventional diamond-coated burs. Lima et al. [19] also observed that the inner walls of the cavity presented a negative surface shape of the ultrasonic burs used, confirming the above-mentioned affirmative.

Analysis of the photomicrographs of the groups in which the burs were only submitted to sterilization/cleaning (SAC, SOC, CC), presented no alteration in structure, differing from those that were used for cavity preparations and sterilized/washed (SA, SO, C). This fact confirms the hypothesis that performing the cavity preparations was responsible for the wear or loss of structure of the burs. Therefore, we suggest that the methods of sterilization alone did not interfere in the durability of the burs.

**CONCLUSION**

Sterilization by oven and autoclave did not influence the cutting effectiveness and durability of CVD and conventional diamond-coated burs.

The conventional diamond-coated burs presented greater structural alterations after performing the cavity preparations and cleaning/sterilization procedures, irrespective of the process used.

**Conflict of Interest**

The authors declare that there is no conflict of interests regarding the publication of this paper.

**REFERENCES**

1. Bellissimo-Rodrigues WT, Bellissimo-Rodrigues F, Machado AA. Infection control practices among a cohort of Brazilian dentists. Int Dent J. 2009 Feb;59(1):53-8.
2. Cheng VC, Wong SC, Sridhar S, Chan JF, Ng ML, Lau SK, et al. Management of an incident of failed sterilization of surgical instruments in a dental clinic in Hong Kong. J Formos Med Assoc. 2013 Nov;112(11):666-75.
3. Bârlean L, Dănilă I, Balcoș C, Sâveanu I, Balan A. Preventive attitudes towards infection transmission in dental offices in North-East Romania. Rev Med Chir Soc Med Nat Iasi. 2012 Oct-Dec;116(4):1209-12.
4. Thomas MV, Jarboe G, Frazer RQ. Infection control in the dental office. Dent Clin North Am. 2008 Jul;52(3):609-28, x.
5. J.A. Cottone, G.T. Tererhalmy, J.A. Molinari. Practical infection control in dentistry. Philadelphia: Lea & Febiger; 1991.
6. Gordon BL, Burke FJ, Bagg J, Marlborough HS, McHugh ES. Systematic review of adherence to infection control guidelines in dentistry. J Dent. 2001 Nov;29(6):509-16.

7. Kohrn WG, Harte JA, Malvitz DM, Collins AS, Cleveland JL, Eklund KJ; Centers for Disease Control and Prevention. Guidelines for infection control in dental health care settings—2003. J Am Dent Assoc. 2004 Jan;135(1):33-47.

8. Gureckis KM, Burgess JO, Schwartz RS. Cutting effectiveness of diamond instruments subjected to cyclic sterilization methods. J Prosthet Dent. 1991 Dec;66(6):721-6.

9. Chung EM, Sung EC, Wu B, Caputo AA. Comparing cutting efficiencies of diamond burs using a high-speed electric handpiece. Gen Dent. 2006 Jul-Aug;54(4):254-7.

10. Fais LM, Pinelli LA, Adabo GL, Silva RH, Marcelo CC, Guaglianoni DG. Influence of microwave sterilization on the cutting capacity of carbide burs. J Appl Oral Sci. 2009 Nov-Dec;17(6):584-9.

11. Miller CH. Tips on preparing instruments for sterilization Am J Dent. 2002 Feb;15(1):66.

12. Spagnuolo G, Ametrano G, D’Antò V, Rengo C, Simeone M, Riccitiello F, et al. Effect of autoclaving on the surfaces of TiN-coated and conventional nickel-titanium rotary instruments. Int Endod J. 2012 Dec;45(12):1148-55.

13. Arcuri MR, Schneider RL, Strug RA, Clancy JM. Scanning electron microscope analysis of tooth enamel treated with rotary instruments and abrasives. J Prosthet Dent. 1993 May;69(5):483-90.

14. Siegel SC, Von Fraunhofer JA. Cutting characteristics of dental diamond burs made with CVD technology. Braz Oral Res. 2006 Apr-Jun;20(2):155-61.

15. Vinski I. Two hundred and fifty years of rotary instruments in dentistry. Br Dent J. 1979 Apr 3;146(7):217-23.

16. Predebon JC, Flório FM, Basting RT. Use of CVDentUS diamond tips for ultrasound in cavity preparation. J Contemp Dent Pract. 2006 Jul;73(6):597-605.

17. Relat Mater. 2002;11(3-6):532-5.

18. Borges CF, Magne P, Pfender E, Heberlein J. Dental diamond burs made with a new technology. J Prosthet Dent. 1999 Jul;82(1):73-9.

19. Fraz Dent J. 1995 Jun;40(3):197-200.

20. Grajower R, Zeitchick A, Rajstein J. The grinding efficiency of diamond technology. Braz Oral Res. 2002 Apr-Jun;20(2):155-61.

21. Oliveira AC, Lima LM, Pizzolitto AC, Santos-Pinto L. Evaluation of the smear layer and hybrid layer in noncarious and carious dentin prepared by air abrasion system and diamond tips. Micromorph. 2002 Jun;73(6):597-605.

22. Blitar DG, Murakami C, Hesse D, Iparac J, Mendes FM. Efficacy of two methods for restorative materials’ removal in primary teeth. J Contemp Dent Pract. 2011 Sep 1;12(5):372-8.

23. Santos-Pinto L, Bortolotto CC, Oliveira AC, Santos-Pinto A, Zuanon AC, Lima LM. The influence of grain size coating and shaft angulation of different diamond tips on dental cutting. J Conserv Dent. 2011 Apr;14(2):132-5.

24. Maccagnanhas Oliveira AC1, Monti Lima L, Santos-Pinto L. Influence of cutting instruments and adhesive systems on hybrid layer formation. Minerva Stomatol. 2012 Mar;61(3):57-63.

25. de Vasconcellos BT, Thompson JY, de Paula Macedo MR, de Oliveira Maia JM, Oda M, Garone-Netto N. Ultrasonic cavity preparation using CVD-coated diamond bur: A case report. Eur J Dent. 2013 Jan;7(1):127-32.

26. Bernardes RA, de Souza Junior J, Duarte MA, de Moraes IG, Bramante CM. Ultrasonic chemical vapor deposition-coated tip versus high- and low-speed carbide burs for apicoectomy: time required for resection and scanning electron microscopy analysis of the root-end surfaces. J Endod. 2009 Feb;35(2):265-8.

27. Furuse AK, de Cunha LF, Runnacles P, Pirlo R, Zielak JC. Using chemical vapor deposition diamond finishing burs for conservative esthetic procedures. Gen Dent. 2013 Jul;61(4):75-7.

28. Woods R, Amerena V, David P, Fan PL, Heydt H, Marianos D. Sterilisation: Part 1. Instrument preparation. FDI World. 1996 Mar-Apr;5(2):7-10.

29. Tate WH, Goldschmidt MC, Ward MT, Grant RL. Disinfection and sterilization of composite polishing instruments. Am J Dent. 1995 Oct;8(5):270-2.

30. Savage NW, Walsh LJ. The use of autoclaves in the dental surgery. Aust Dent J. 1995 Jun;40(3):197-200.

31. Grajower R, Zeitlich R, Rajstein J. The grinding efficiency of diamond finishing burs. J Prosthet Dent. 1979 Oct;42(4):422-8.

32. Vieira AS, dos Santos MP, Antunes LA, Primo LG, Maia LC. Preparation time and sealing effect of cavities prepared by an ultrasonic device and a high-speed diamond rotary cutting system. J Oral Sci. 2007 Sep;49(3):207-11.

33. Pereira Nogueira P, Cavalli V, Liporoni PC, do Rego MA. Hybrid layer width after conventional diamond, carbide and ultrasound CVD burs. J Clin Pediatr Dent. 2012 Fall;37(1):53-7.

34. Cooley RL, Marshall TD, Young H, Huddleston AM. Effect of sterilization on the strength and cutting efficiency of twist drills. Quintessence Int. 1990 Nov;21(10):919-23.

35. Sprain SJ, De Meurie P, Ireland EJ, Sendon DP, et al. Cutting effectiveness of carbide burs following multiple steam autoclaving cycles. Gen Dent. 2011 Jan-Feb;59(1):53-8.

36. Vanderlei AL, Borges AL, Cavalcanti BN, Roda SM. Ultrasonic versus high-speed cavity preparation: analysis of increases in pulpal temperature and time to complete preparation. J Prosthet Dent. 2008 Aug;100(2):107-9.

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