Comparison of cutting efficiencies between electric and air-turbine dental handpieces

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Statement of problem. Dentistry is gravitating toward the increased use of electric handpieces. The dental professional should have sufficient evidence to validate the switch from an air-turbine handpiece to an electric handpiece. However, there is little research quantifying the cutting efficiency of electric and air-turbine handpieces. Studies that do quantify cutting efficiency typically do so with only a single material.

Purpose. The purpose of this study was to compare the cutting efficiency of an electric handpiece and an air-turbine handpiece, using various materials commonly used in dentistry.

Material and methods. Seven materials: Macor (machinable glass ceramic), silver amalgam, aluminum oxide, zirconium oxide, high noble metal alloy, noble metal alloy, and base metal alloy, were each cut with a bur 220 times; 110 times with an electric handpiece, and 110 times with an air-turbine handpiece. The weight difference of the material was calculated by subtracting the weight of the material after a cut from the weight of the material before the cut. The cutting efficiency was calculated by dividing the weight difference by the duration of the cut (g/s). Data were analyzed by a 2-way analysis of variance followed by Tukey's Honestly Significant Difference (HSD) test (α=.05).

Results. The electric handpiece cut more efficiently than the air-turbine handpiece (F=3098.9, *P*<.001). In particular, the high noble metal alloy, silver amalgam, and Macor were cut more efficiently with the electric handpiece (0.0383 ±0.0002 g/s, 0.0260 ±0.0002 g/s, and 0.0122 ±0.0002 g/s, respectively) than with the air-turbine handpiece (0.0125 ±0.0002 g/s, 0.0142 ±0.0002 g/s, and 0.008 ±0.0002 g/s, respectively).

Conclusions. The electric handpiece is more efficient at cutting various materials used in dentistry, especially machinable glass ceramic, silver amalgam, and high noble alloy, than the air-turbine handpiece. (J Prosthet Dent 2010;103:101-107)

Clinical Implications

The results of this study may provide the clinician additional reason to use an electric handpiece over an air-turbine handpiece, as the electric handpiece is significantly more efficient at cutting various materials than is the air-turbine handpiece.

One of the most significant advances in dentistry has been the development of the dental handpiece. In 1868, Green introduced the pneumatic handpiece.[1] This was an air-driven handpiece powered by foot bellows, which provided air through rubber tubes to the handpiece. However, Green's instrument was not nearly as efficient as the Morrison foot pedal engine introduced in 1871, which was the first patented and commercially available dental engine, and which revolutionized the practice of dentistry.[1] The early handpieces of the 19th century were difficult to control and operated at low speeds, making excavations tedious.[2] In fact, the

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Morrison handpiece operated at 600 to 800 revolutions per minute (rpm).[1] Fortunately, the turn of the century was marked by vast improvements to these earlier handpieces.

The most notable handpiece of the 20th century was a high-speed air-driven contra-angle handpiece introduced by Borden in 1957. The Borden Airotor was an air-turbine handpiece that obtained speeds of up to 300,000 rpm. This handpiece was an immediate commercial success and began a new era of high-speed dentistry.[3] Both diamond rotary cutting instruments and carbide burs became widely accepted with the development of the Borden Airotor. Interestingly, much of the bur testing comparing cutting efficiencies was actually performed before the advent of high-speed dental handpieces.[4-7] Nevertheless, dental burs continue to be studied.

The cutting efficiency of rotary instruments can be considered as the maximum capacity for removal of dental structure with the minimum of effort, over a determined period of time.[8] Typically, studies compare the cutting efficiencies of carbide burs and diamond rotary cutting instruments,[7,9-14] for the purpose of comparing different carbide burs to each other, comparing different diamond rotary cutting instruments to each other, or comparing carbide burs to diamond rotary cutting instruments. In addition, studies may vary by testing these burs using different materials.

Most of the studies comparing the cutting efficiency of different burs on different materials have used the high-speed air-turbine handpiece.[7,9-16] Dyson and Darvell[17] compared the performance of 14 conventional air-turbine handpieces to that of 2 disposable air-turbine handpieces. Although electric motor handpieces have been in use since the 1960s, they have not gained popularity in the United States. High-speed air-turbine handpieces remain the primary tooth-cutting instrument used in the United States, despite the popularity of electric motor handpieces in other parts of the world.[18] An extensive search of the literature disclosed few studies in which the cutting efficiency was compared between an electric handpiece and an air-turbine handpiece. In a study by Kenyon et al,[19] dental students were asked to make Class I cavity preparations with both the electric and the air-turbine handpiece. The quality of each preparation was evaluated by a single faculty member and then graded. The mean scores earned by students using the electric handpiece versus the air-turbine handpiece were not significantly different. Eikenberg[20] compared the cutting efficiency of the electric motor handpiece versus the air-turbine handpiece using Macor (Corning, Inc, Corning, NY), a glass ceramic material used to simulate enamel. Two different types of electric motor handpieces were compared to an air-turbine handpiece, using 2 different amounts of force. Results revealed that, for both forces, electric motor handpieces demonstrated greater efficiency in cutting the machinable glass ceramic than the air-turbine handpiece.

Ercoli et al[21,22] also compared the cutting efficiency between the electric handpiece and air-turbine handpiece using Macor, in addition to comparing the mean simulated pulp chamber temperature and required load necessary to perform the cutting action. Ercoli et al[21] first compared cutting efficiency, required cutting action load, and pulp chamber temperatures of numerous diamond rotary cutting instruments of various types, grits and design, to a carbide bur (Great White Ultra; SS White Burs, Inc), using an air-turbine handpiece. In another study,[22] the same tests were performed with an electric handpiece, and the results of each handpiece were compared. Specific to cutting efficiency between the 2 handpieces, the results showed that the electric handpiece had a higher cutting efficiency than the air-turbine handpiece, especially as the preparation progressed, and when used with the carbide bur.

The purpose of the present study was to quantify the cutting efficiencies of air-turbine handpieces versus electric-motor handpieces using 7 materials: aluminum oxide ceramic, zirconium oxide ceramic, high noble metal alloy, noble metal alloy, base metal alloy, silver amalgam, and machinable glass ceramic. These materials, representing those used clinically, were cut with both types of handpieces, with a bur specifically recommended by a bur manufacturer for each particular material. The null hypotheses were that there would be no significant difference in cutting efficiency between the 2 different handpieces used, and that there would be no significant difference in the cutting efficiency among the various materials used.

MATERIAL AND METHODS

A telephone survey was conducted by contacting the technical department of a manufacturer of dental burs (Brasseler USA, Savannah, Ga). The authors inquired as to which diamond rotary cutting instrument or carbide bur the manufacturer recommended for each test material. Based on this survey, a list of burs, and the material each was to be used on, was compiled (Table I).

A high-speed electric motor handpiece (Ti-Max NL400; Brasseler USA) and a high-speed air-turbine handpiece (KaVo OPTItorque LUX3 649B; KaVo America Corp, Lake Zurich, Ill) were used in the study. As previously described,[12] each handpiece was placed in a brass cylinder attached to an L-shaped, clear Plexiglas (Evonik Industries, Essen, Germany) acrylic, vertical block by a frictionless bearing. A stainless steel holder attached to the base of the cutting apparatus rigidly held the cutting specimen in place. The air-turbine handpiece was operated at a speed of 340,000 rpm with a constant air pressure of 0.23 MPa (33 psi) under a coolant water spray of 20 ml/min. The electric

Table I. Carbide burs and diamond rotary cutting instruments and cutting times used in study

Bur Number	Type	Manufacturer	Material Cut	Duration of Cut(s)
Super Course Diamond (5847.31.014)	diamond	Brasseler USA, Savannah, Ga	Macor	5
DuraCut Diamond (6847DC.31.016)	diamond	Brasseler USA	zirconium oxide aluminum oxide	30 45
Amalgam Cutter (H32.31.012)	carbide	Brasseler USA	silver amalgam	5
Crown Remover (H34)	carbide	Brasseler USA	high noble metal noble metal base metal	5 60 60

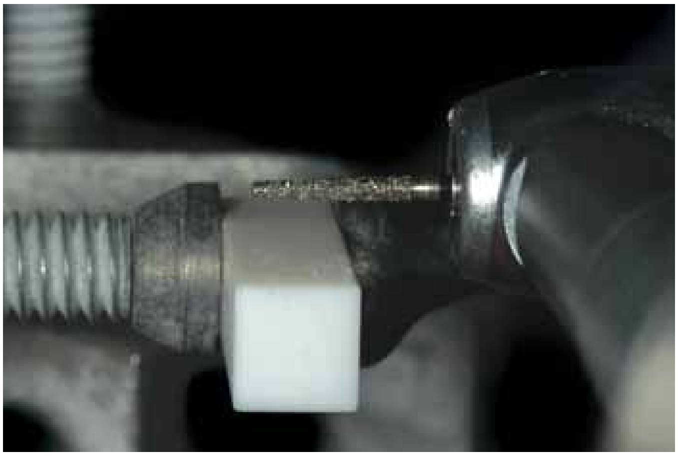
handpiece was operated at a speed of 200,000 rpm, as recommended by the manufacturer, under the same conditions. The applied cutting force (at the bur-material interface) was achieved using a load of 0.90 N, or 91.5 g (an average cutting force used by dentists),[12] by attaching a weight of 147.5 g to a location on the handpiece that was 40 mm from the bur-handpiece interface. The cutting procedures, measurements, and handling of the materials were all performed by a single operator.

The materials to be tested were blocks of aluminum oxide ceramic implant abutment material (CerAdapt; Nobel Biocare AB, Göteborg, Sweden), zirconium oxide ceramic implant abutment material (ZiReal; Biomet 3i, Palm Beach Gardens, Fla), high noble metal alloy (Classic IV; Jensen Dental, North Haven, Conn), noble metal alloy (PG-200; Baker Dental Corp, Lake Zurich, Ill), base metal alloy (Rexillium III; Jeneric/Pentron, Inc, Wallingford, Conn), silver amalgam (Contour Fast Set; Kerr Corp, Orange, Calif), and machinable glass ceramic (Macor; Corning, Inc, Corning, NY).

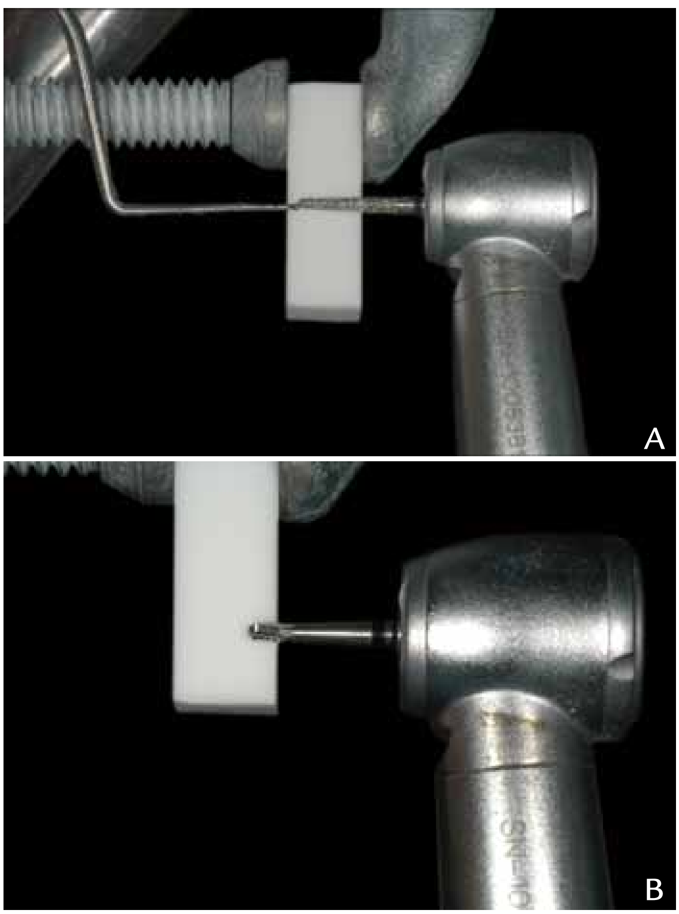
The aluminum oxide ceramic implant abutment and zirconium oxide ceramic implant abutment raw materials were obtained as rectangular blocks (12 x 6 x 6 mm) from their respective manufacturers. The metal alloys were fabricated from a standardized 12 x 6 x 6-mm mold using acrylic resin patterns (Duralay; Reliance Dental Mfg Co, Worth, Ill), invested, and cast using conventional procedures,[23] in accordance with manufacturer specifications. The silver amalgam blocks were fabricated by condensing the silver amalgam into a standardized 12 x 6 x 6-mm mold former made of autopolymerizing acrylic resin (Jet; Lang Dental Mfg Co, Inc, Wheeling, Ill). The machinable glass ceramic blocks were the only specimens that differed in size. This material (Macor; Corning, Inc) was received from the manufacturer as bars, approximately 100 x 7 x 7 mm in size, which were cut into smaller 20 x 7 x 7-mm blocks using a diamond disc (Brasseler USA).

Each block of material was secured in an adjustable frame, to allow the entire thickness of each block to be cut through, with the holding frame rigidly mounted in a stainless steel holder attached to the base of the cutting assembly. The rectangular blocks were positioned parallel to the floor. The long axis of the bur was parallel to the block of material and pulled perpendicularly down into the material (Fig. 1). The burs (Brasseler USA), and the materials for which each bur was recommended, are listed in Table I.

The handpiece, secured in the brass mounting, was sprayed with lubricant for 1 second; KaVo Spray lubricant (KaVo America Corp) for the air-turbine handpiece, and Pana Spray lubricant (NSK Nakanishi, Inc, Kanuma, Japan) for the electric handpiece. The test bur was placed into the handpiece, and the handpiece was run for 1 minute to flush the water line of all lubricant. The handpiece was then run at its maximum speed, with the head directed into a graduated cylinder to measure the rate of coolant spray for 1 minute, and adjustments were made until a 20 ml/min flow rate was achieved. This process was performed with both the air-turbine handpiece and the electric handpiece. The diamond rotary cutting instruments and carbide burs (Table I) were aligned to the block of material so that the end of the bur was 1 mm away from the edge of the specimen. This measurement was made with a periodontal probe (Maryland/Moffitt Color-Coded Probe; Hu-Friedy Intl, Chicago, Ill) (Fig. 2, A). Every part of the bur contacting the substrate was a cutting surface. The carbide burs with short cutting surface lengths (Crown Remover; Brasseler USA) were aligned so that the entire cutting surface of the bur was placed on the block of material. This was necessary because the cutting surface of these burs is much shorter than that of the other burs used in this study (Fig. 2, B).



1 Bur cutting surface shown paralleling material.



2 A, Alignment of bur 1 mm from edge of substrate. B, Alignment of carbide burs with short cutting surface lengths on block.

Cutting efficiency was defined as the difference in weight divided by the length of cutting time (g/s). Before each test run, the specimen block was rinsed for 1 minute, dried with compressed air, and then weighed using a scale (Denver X-100A; Denver Instrument Corp, Denver, Colo). This weight represented the weight of the material at baseline. After arranging the material and the handpiece onto the apparatus, the bur was allowed to cut the material for a specific number of seconds using a timer (Jarden Corp, Rye, NY). The specific amount of time used for each material (Table I) was determined by cutting a specimen of each material with its specified bur and with each handpiece. A time, shorter than the time it took the faster handpiece to cut through the entire width of the material, was assigned. At the end of this time period, the materials were rinsed and dried before being weighed again. The new weight represented the weight of the material after the predetermined cut duration (in seconds). The cutting efficiency was then calculated by dividing the difference in weight before and after cutting by the cutting duration. Following each specimen testing, the handpieces and the apparatus were evaluated to ensure testing conditions remained the same. Handpieces were again lubricated and operated for 1 minute to flush the water line. The flow rate of the coolant spray was adjusted to maintain 20 ml/min, before the next test. Each bur was used only once to standardize testing conditions. Each material was cut 110 times with each handpiece. Therefore, the total number of cuts in the study was 220 cuts per material.

This data set displayed neither homogeneity of variance nor normality. Therefore, the data were transformed to a rank-based configuration. This allowed the data to be analyzed using a 2-way analysis of variance (ANOVA) followed by Tukey's HSD test (α=.05), allowing interactions between materials and handpieces to be determined.

RESULTS

The results of this study demonstrated that the electric handpiece was more efficient than the air-turbine handpiece in cutting the dental materials tested (F=3098.9, P<.001). The electric handpiece was significantly more efficient in cutting the material, 0.0114 ±0.0001 g/s (mean ± standard deviation) than the air-turbine handpiece, 0.0052 ±0.00001 g/s (Table II). Some materials were cut more easily than others (F=5292.9, P<.001). The handpieces cut high noble metal alloy most efficiently (0.0260 ±0.0001 g/s), followed by silver amalgam (0.0201 ±0.0001 g/s), and then the machinable glass ceramic (0.0101 ±0.0001 g/s). There was no significant difference in mean cutting efficiency between aluminum ox-

Table II. Cutting efficiency of the air-turbine and electric handpieces

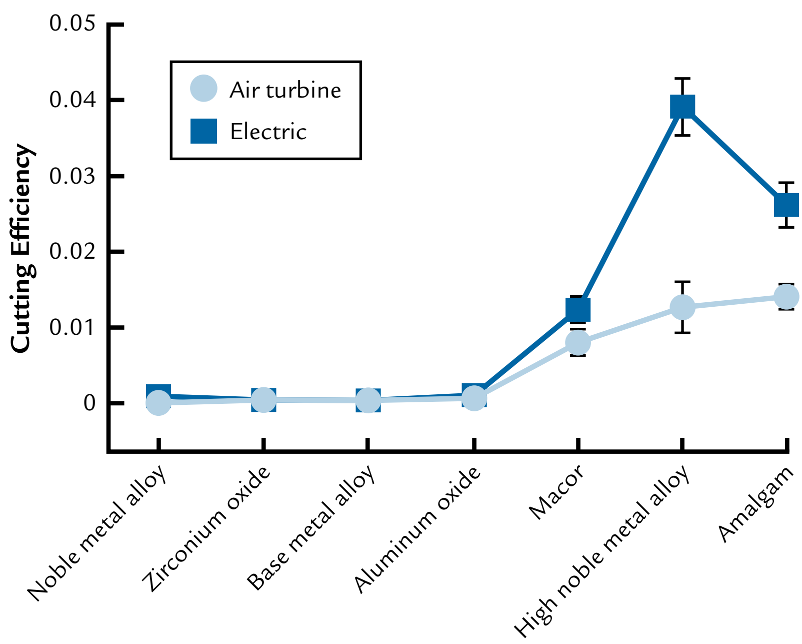
Handpiece	Specimen Size	Mean (g/s)	SD
Air turbine	770	0.0114	0.00008*
Electric	770	0.0052	0.00008

*F = 3098.9, P<.001

Table III. Cutting efficiency (n=220) of different materials

Material	Mean (g/s)	SD
High noble metal alloy[a]	0.0256	0.0001
Silver amalgam[b]	0.0201	0.0001
Macor[c]	0.101	0.0001
Aluminum oxide[d]	0.0008	0.0001
Noble metal alloy[d]	0.0005	0.0001
Zirconium oxide[d]	0.0005	0.0001
Base metal alloy[d]	0.0003	0.0001

Materials with same superscript are not significantly different from each other; F=5292.8, P<.001.



3 Interaction between handpieces and materials tested. Error bars signify standard deviations.

ide (0.0008 ±0.0001 g/s), noble metal alloy (0.0005 ±0.0001 g/s), zirconium oxide (0.0005 ±0.0001 g/s), and base metal alloy (0.0003 ±0.00001 g/s) (Table III).

Most importantly, there was a significant interaction in cutting efficiency between the type of material cut and the handpiece used (F=1119.8, P<.001) (Fig. 3; Table IV). The high noble metal alloy, silver amalgam, and machinable glass ceramic were cut more efficiently with the electric handpiece (0.0388 ±0.0002 g/s, 0.0260 ±0.0002 g/s, 0.0122 ±0.0002 g/s, respectively) than with the air-turbine handpiece (0.0125 ±0.0002 g/s, 0.0142 ±0.0002 g/s, 0.0079 ±0.0002 g/s, respectively). For aluminum oxide, zirconium oxide, noble metal alloy, and base metal alloy, there was no difference in cutting efficiency between the electric handpiece and the air-turbine handpiece (Fig. 3).

Table IV. Two-way ANOVA for cutting efficiency of 2 handpieces and different materials

Source	Type III Sum of Squares	*df*	Mean Square	F	*P*
Materials	0.151	6	0.025	5292.9	.001
Handpieces	0.015	1	0.015	3098.9	.001
Material × handpiece	0.032	6	0.005	1119.8	.001

DISCUSSION

The results of this study demonstrated that there was a significant difference between the 2 handpieces used. There was also a significant difference in the cutting efficiency between different materials, and there was a significant interaction between the material cut and the handpieces used. Therefore, the null hypotheses were rejected.

A review of the literature revealed only a few studies that compared the cutting quality and/or efficiency of the electric handpiece to that of the air-turbine handpiece. Kenyon et al[19] compared the quality of Class I cavity preparations made by dental students with both the electric and the air-turbine handpieces, but did not discuss the cutting efficiencies of the 2 handpieces. The Eikenberg study[20] was designed to compare the cutting efficiency of the electric handpiece and the air-turbine handpiece. Two different electric handpieces were compared to an air-turbine handpiece, using machinable glass ceramic as the specimen, while applying 2 different forces. The author found that the electric handpieces were more efficient at cutting machinable glass ceramic, at both forces, than the air-turbine handpiece. Ercoli et al[21,22] compared the cutting efficiency, as well as the resultant simulated pulp temperature and required applied load, between the electric handpiece and air-turbine handpiece. While using a variety of diamond rotary instruments and a carbide bur, with Macor as the specimen, the author found the electric handpiece to have a higher cutting efficiency than the air-turbine handpiece, especially as the cutting progressed, and when using the carbide bur versus the various diamond rotary instruments.

Consistent with the results of Eikenberg and Ercoli et al,[20,22] the current study demonstrated that the electric handpiece was more efficient than the air-turbine handpiece. In addition, the interaction showed that the cutting efficiency of the electric handpiece was noticeably better on the high noble metal alloy, silver amalgam, and machinable glass ceramic specimens than the air-turbine handpiece. The cutting efficiency for the other specimens, aluminum oxide, zirconium oxide, noble metal alloy, and base metal alloy, were not significantly different with either handpiece.

The smaller differences found with these materials compared to those found with the high noble metal alloy, silver amalgam, and machinable glass ceramic may be related to the hardness of each of these materials. The Vicker's hardness values for silver amalgam, high noble metal alloy, and machinable glass ceramic are 120, 220, and 250 kg/mm^2, respectively, as purported by the manufacturers. However, the values for noble metal alloy, base metal alloy, zirconium oxide, and aluminum oxide, as purported by the manufacturers, are 360, 360, 1200, and 1440 kg/mm^2, respectively. The harder the material, the harder it will be to cut. Clinically, when a dentist cuts a harder material, more force is placed on that material to cut it more efficiently. The force used in this study (147.5 g, or 91 g at the bur tip) may have been inadequate to allow the handpieces to cut the harder material efficiently. Therefore, the use of greater force may have resulted in a more noticeable difference between the 2 types of handpieces. Similarly, the ductility of the materials may have had a role. The more ductile the material, the more efficiently it is cut. Howell[16] stated that the cross-cut fissure carbide bur had the advantageous feature of "snatching" the metal surface that was ductile in nature. This characteristic was also recognized by Miyawaki,[11] who stated that it was more difficult to cut alloys that were harder and less ductile.

Advocates of the electric handpiece have suggested that the constant torque and, therefore, lack of "stalling" from the electric handpiece, makes it more efficient at cutting than the air-turbine handpiece.[18] Although complete stalling was not experienced in this study, it is possible that the air-turbine handpiece slowed down throughout some of the cuts or several times during a cut. Unfortunately, this is an aspect that could not be measured in the current study; therefore, this suggestion is speculative. It should also be noted that the handpieces were run at different rpms. The air-turbine handpiece was run at 340,000 rpm, whereas the electric handpiece was run at 200,000 rpm. Even at the lower rpm, the electric handpiece performed as well as, if not better than, the air-turbine handpiece. It is expected that at equal rpms, the electric handpiece may be even more efficient at cutting the different materials. In addition, electric handpieces are considered heavier than air-turbine handpieces.[18] The heavier electric handpiece may place more force on the specimen, resulting in a greater cutting efficiency.

There are several limitations to this study. The carbide burs with short cutting surface lengths (Crown Remover; Brasseler USA) were placed so that the entire cutting surface was positioned on the block of material. This was done by visually approximating the placement of the bur. This is not as exacting as using a periodontal probe to measure the placement. Slight differences in placement of the carbide burs with short cutting surface lengths could result in different cutting efficiencies. Involvement of any part of the shank would make the cutting efficiency lower. Standardization of the cuts was attempted by placing the cutting edge of the bur parallel to the block of the material to be cut. This process is dependent on the operator, and could incur error as well. The bur cutting surface that is not parallel to the block of material may cut less efficiently, producing varying results. After each cut, the block of material was removed from the clamp, washed, dried, and then weighed. The block was then placed back into the clamp, or a new block of material was placed into the clamp. Placement of the block into the clamp was intended to replicate, as nearly as possible, the placement of the block for the previous cut. The material was placed as close to the center of the clamp as possible. However, any deviation from the center may have resulted in the application of different forces, thus, changing the cutting efficiency.

The current study was able to quantify the cutting efficiency of the electric handpiece and the air-turbine handpiece. The quantification and comparison of the cutting efficiency of the electric handpiece and the air-turbine handpiece on various materials used in dentistry, as in this study, suggest that the electric handpiece is more efficient than the air-turbine handpiece.

CONCLUSIONS

This study was performed to determine which handpiece, the electric or the air-turbine handpiece, is more efficient at cutting various materials used in dentistry. Within the limitations of this study, the results revealed that there was a significant difference in cutting efficiency between the electric handpiece and the air-turbine handpiece, especially for particular materials. The electric handpiece is more efficient than the air-turbine handpiece at cutting high noble metal alloy, silver amalgam, and machinable glass ceramic.

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