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Cutting efficiency of different dental diamond rotary instruments for sectioning monolithic zirconia and lithium disilicate crowns

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Abstract

Background The aim of this study was to determine the cutting efficiency of different diamond rotary instrument types for sectioning monolithic zirconia and lithium disilicate anatomical crowns.

Materials and methods The study used 30 diamond rotary instruments divided into three groups: Zirconia cutting diamond bur (White Z), super coarse grit diamond bur (KBlack), and medium coarse grit diamond bur (KBlue); Two subgroups were assigned based on the crown materials including monolithic zirconia (5YSZ) and lithium disilicate (e.max) ceramics. The cutting efficiency was assessed by measuring the time required to fully section the crowns, followed by scanning electron microscopy (SEM) and energy-dispersive spectroscopy (EDS) of the dental burs before use and after every sectioned crown. A three-way ANOVA examined the effects of bur type, material type, and sectioning stage. If interaction exists, one-way ANOVA was used to compare the different subgroups, followed by the Tukey post hoc test. The significance level was assigned at $\alpha \leq 0.05$.

Results The results exhibited various cutting efficiencies among diamond rotary instruments and ceramic crown materials. White Z demonstrated superior cutting efficiency of zirconia crown compared with KBlack and KBlue for the first cutting cycles ($p \leq 0.05$); the results tend to be more comparable at the third cutting cycle. However, the super coarse diamond bur exhibited higher efficiency in cutting lithium disilicate crowns than white Z and KBlue burs through all three cutting cycles($p \leq 0.05$). The diamond bur-cutting efficiency diminished after each use, irrespective of the bur type or the crown material ($p \leq 0.05$); this was represented by the reduction of carbon and increased nickel matrix ratio after each bur usage.

Conclusion White Z diamond bur showed higher cutting efficiency of zirconia in the first two cutting cycles; super coarse diamond bur is more efficient for cutting lithium disilicate crown in all of the cutting cycles. The amount of diamond on the burs reduced after each use, with no great impact on the material type when sectioning lithium disilicate and 5YSZ crowns.

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Clinical significance This study provides valuable insights for dental practitioners in selecting the appropriate diamond rotary instrument for crown sectioning. Practitioners can minimize the risk of damage and reduce the time required for crown removal, improving patient outcomes.

Keywords Ceramic, Cutting effecincy, Diamond burs, Lithum dislicate, Zirconia

Background

There has been a great shift toward metal-free dental restorations and prostheses due to their high esthetic characteristics relative to cast metal and metal-ceramic restorations and prostheses, biocompatibility, and good mechanical properties [1]. Different ceramic materials are being applied in the dental field, and they belong to three modern categories: resin matrix ceramics, glass matrix ceramics, and oxide ceramics [2]. The latter two categories are mostly applied in prosthetic dentistry, including zirconia polycrystalline and lithium disilicate ceramics, the most popular and widely utilized materials for dental crown fabrications [3, 4].

Lithium disilicate crowns are widely preferred in the esthetic zone due to their commendable esthetic properties [5]. Although they possess comparatively lower mechanical properties, recent studies have indicated their remarkable survival rates when employed in posterior teeth [6, 7]. While zirconia ceramic is applied mainly as a framework material for all-ceramic restorations due to its superior strength and enhanced aesthetics compared to metal-ceramic restorations [8, 9]. Furthermore, nowadays, monolithic zirconia restorations have become the predominant solution that does not require the application of veneering material, avoiding the chipping or fracture of the veneering ceramic [10].

Several clinical complications may require the removal of ceramic crowns. The large number of exposed dentinal tubules on prepared teeth for ceramic crowns increases the likelihood of contamination and damage [11, 12]. Infection, contamination, or hyperthermia can cause pulpal irritation and increase pulpal blood flow [13]. This may result in symptomatic or asymptomatic reversible pulpitis, which typically subsides after temporization or a short period. Pulpal trauma is unavoidable, but its severity can be mitigated through proper isolation and suitable water cooling. However, in rare cases, irreversible pulpitis or asymptomatic necrosis of the pulpal tissue may occur, especially in abutments with large or multiple restorations, particularly in elderly patients. In such cases, access cavity preparation may be necessary [14, 15]. If primary endodontic treatments are required after cementation, the pulp may be accessed through the ceramic crown, thus saving time and costs associated with new crown fabrication [15]. Monolithic zirconia crowns are less prone to damage during access cavity preparation, but veneered zirconia crowns and glass ceramic crowns may develop chipping and damage that require complete removal and replacement [16]. Removing luted dental restorations, particularly full crowns, can be challenging and time-consuming, requiring careful evaluation and specialized techniques [17]. Nevertheless, the removal of dental crowns may be recommended in various scenarios, including cases of recurrent caries, old restorations, faulty cementations, and defective crowns or prostheses [18].

Various methods are used to remove dental crowns, including the Richwil crown and fixed partial dental prosthesis remover, ultrasonic devices, crown tractors, and sections through the crown [19]. Cutting through the crown with dental diamond rotary instruments (burs) is considered a destructive removal method [20]. However, it is commonly used to prevent further damage to the prepared teeth, particularly for highly retentive, professionally seated, and cemented crowns. These burs offer a secure, efficient, and skilled cutting approach, reducing the risk of harm to the dental structure [21]. Moreover, the exceptional strength of zirconia restorations brings a challenge during the cutting process, often necessitating multiple rotary instruments and resulting in a time-consuming procedure [22].

Choosing a suitable bur depends on various qualitative factors, such as cutting efficiency and wear of the cutting instrument [17, 22]. In dental practice, there is a substantial decline in cutting efficiency with repeated use of burs regardless of the bur type [23]. Moreover, the coarseness of dental bur is well known for its high efficiency of cutting, being indicated for more aggressive cutting of tooth structure [24], while the behavior of different dental diamonds on monolithic ceramic might still vague. Not to mention that the cutting diamond particles are attached to the rotary instrument cutting end by embedding in a metal matrix; the resistance to wear relies on the speed of detachment of these diamond particles from the metal matrix, which might be a matter of fabrication quality and depend on the degree of adherence of these diamond particles to the surrounding matrix. This leads to increasing ambiguity about the efficiency of different brands of diamond instruments when cutting through dental ceramic crowns [25]. Not to mention the introduction of specialized diamond instruments produced to cut through certain materials such as zirconia crowns [25, 26], where to our knowledge there hasn't been strong evidence of their superiority over the conventional diamond cutting instruments.

Regarding the cutting cycles, no specific literature indicates the maximum limit for changing diamond burs during or after dental procedures [27, 28]. Recently, there has been a growing demand for cost-effective disposable dental instruments that provide efficient performance. Manufacturers consider single-use burs more economical than sterilization procedures [29]. The previous studies [22, 25, 30, 31] on the cutting efficiency of rotary instruments were conducted using non-anatomical samples of blocks or specimens that do not reflect real-life scenarios. Furthermore, many of these studies did not include oral condition simulation, such as thermocycling or other relevant conditioning of the specimens. Thermocycling, even if it seems harmless to materials such as dental zirconia, might induce structural changes under low thermal degradation, for 3 mol%Y-TZP, being evident in the significant increase in translucency after thermocycling [32], thus might not be of higher impact clinically, where this effect can be aggravated by thermodynamic aging [33]. Moreover, translucent zirconia as 4- and 5-YSZ might be less affected by thermocycling, while it has a major impact on lithium disilicate ceramic's microhardness, optical properties, and surface roughness [34]. Consequently, the findings of these studies on the cutting efficiencies of these rotary instruments might be subject to change if the anatomical crown is cemented and exposed to oral cavity condition simulation, representing the closest anatomical form; compared to studies conducted on laboratory bar or block specimens; and environment related to the patient's mouth when removing a cemented dental crown.

The presented study aimed to determine the efficiency of different dental diamond rotary instruments and their cutting speed for sectioning monolithic zirconia and lithium disilicate crowns. The null hypotheses assumed that: (1) The cutting time is comparable for both zirconia and lithium disilicate crowns. (2) Different cutting instruments possess the same cutting efficiency, irrespective of the crown material. (3) The cutting burs will show no signs of wear after three cutting cycles.

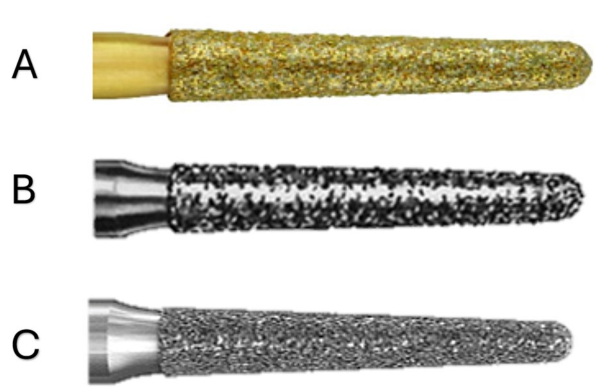

Fig. 1 Diamond rotary instruments used, (A), White Z; (B), KBlack; and (C), KBlue burs

Materials and methods

The sample size calculation was accomplished using the G Power statistical program (G* power; Heinrich Heine University Düsseldorf). A total sample size of 30 rotary instruments was considered adequate, with 5 rotary instruments for the subgroups, identifying a substantial effect size (f=1.98) with a targeted actual power (1-β error) of 0.95 (95%) and a significance level (α error) of 0.05 (5%) for a two-sided hypothesis test.

A total of 30 diamond rotary instruments were divided into 3 groups according to type and coarseness of diamond rotary instrument as follows: (1) White Z; Zirconia cutting diamond bur with round end taper GWZ 856−018 with head size 018 1/10 mm, cutting length 8.0 mm, (1145 Towbin Avenue Lakewood, N J, USA), (2) KBlack: Super coarse grit diamond bur; 5856 with head Size 018 1/10 mm, cutting length 8.0 mm (Black band diamond, Komet USA LLC, Rock Hill, SC), (3) KBlue: medium coarse grit diamond bur; 8856 with Head Size 018 1/10 mm and Cutting Length 8.0 mm (Blue band diamond, Komet Dental USA LLC, Rock Hill, SC). Two subgroups (5 Instruments for each) were assigned for the crown materials: monolithic zirconia and lithium disilicate ceramics crowns. Each instrument of the 3 types (White Z, KBlack, and KBlue) was used to section 3 of the zirconia or lithium disilicate crowns for a total of 90 measurements. Figure 1 shows the diamond rotary instruments used.

A typodont mandibular right first molar (KaVo Dental, Kita Shinagawa, Tokyo, Japan) was selected to prepare full ceramic crowns. The tooth was prepared with an occlusal reduction of 2 mm at the functional cusps, 1.5 mm at the nonfunctional cusps, and an axial reduction of 1 mm. A 4.5-mm occlusal-gingival height was established. The total convergence angle was set at 12 degrees and a circumferential margin with a 1.0-mm chamfer finish line. For standardized preparation, the tooth was prepared using a BEGO milling machine [35]. To ensure a standard sectioning reference point, two dimples were generated at the cemento-enamel junction level, on the middle of the buccal and the lingual surfaces.

The prepared typodont tooth was duplicated to form 30 resinous abutments to standardize the preparation for all the groups. The tooth was scanned using a laboratory scanner (Map 600 scanner, Amann Girrbach AG, Austria) and duplicated using a stereolithography 3D printer (Form 3B, Formlabs Co., United States), using a specialized dental model liquid (photopolymer resin) that solidified upon exposure to a laser beam of a specific temperature, resulting in the creation of 90 identical prepared resin molars.

A total of 90 crowns were milled out of two different ceramic materials. Forty-five crowns were milled out from super high translucent monolithic zirconia ceramic discs; 5 mol%YSZ (Ceramill Zolid fx white; Amann Girrbach AG, Austria), and 45 crowns were milled out from lithium disilicate glass-ceramic blocks (IPS e.max CAD, Ivoclar, Schaan, Liechtenstein). The milling procedure was accomplished by a 5-axis CAD/CAM milling machine (Ceramill; Amann Girrbach AG, Austria); the process followed the manufacturer's instructions.

After finishing and sintering the milled crowns, it has to be sure they fit the 3D-printed resin abutments perfectly. For lithium disilicate crowns, the luting procedure was done using self-etch/self-adhesive resin cement with a clean-up indicator (Maxcem Elite Chroma, Kerr Corporation, Italy). The intaglio surfaces of lithium disilicate crowns were etched using 9.5% hydrofluoric acid (Porcelain Etch, Bisco, Schaumburg, USA) for 20 s, then rinsed with water and dried with oil-free and moisture-free air. The Silane bond (Silane bond Enhancer, Plupodent Corporation, Watertown, USA) was applied on the etched ceramic surface and left to dry. The self-adhesive resin cement was then applied to the intaglio surfaces of the crowns and seated over the resin abutments with a uniform force of 5 kg [36]. The excess cement was removed following the manufacturer's instructions. For Zirconia crowns, the internal surface of the crown was roughened with air-born-particle abrasion with 50 µm alumina (Al_2O_3) at a pressure of 60 psi (0.4 MPa) with a distance of 10 mm for 10 s (Cobra 50 µm, white; Renfert GmbH, Hilzingen, Germany) [37]. The luting procedure is the same as in the lithium disilicate group.

The crown specimens were subjected to 5000 thermocycles, with 5 to 55 °C fluctuant temperature, 60-second bath cycles, and 10-second dwell time, simulating 6 months of intraoral service (SD Mechatronic, Thermocycler, Westerham, Germany) [38].

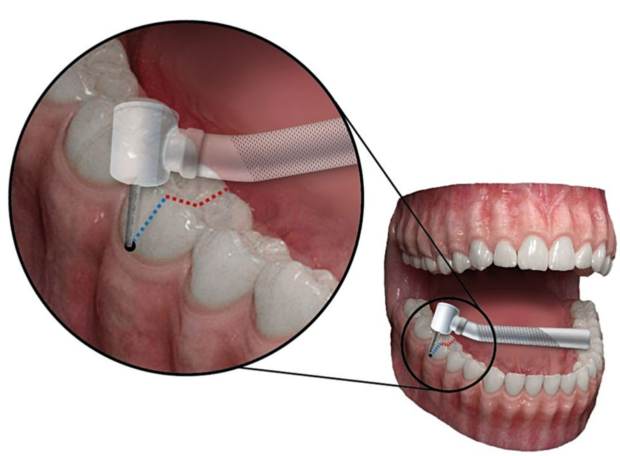

Fig. 2 Illustration of the performed sectioning process

After 48 h, the sectioning of the cemented ceramic crowns was done. An operator performed the laboratory procedure inside the dummy head using an electrically driven motor (Bien Air MCX, LED; Irvine, CA, USA) and a speed regulating handpiece (Bien Air EVO.15 1.5 L) to maintain a constant cutting speed. A running speed of 200,000 rpm was utilized. Before every crown sectioning process, the handpiece was cleaned and lubricated according to the manufacturer's instructions. Immediately before crown sectioning, the handpiece was thoroughly flushed with coolant (water) for 60 s to remove any cleaning solution or oil. During this study, a 40 mL/min coolant flow rate was maintained [21, 39].

The same operator performs sectioning under the same conditions and sectioning path. Once contact between the bur and the crown was established, the stopwatch (Casio F91 W1, Casio America Inc, Dover, NJ) was initiated. The cutting procedure commenced at the middle of the reference point on the buccal surface margin, progressing axially across the buccal, occlusal, and lingual aspects until the lingual reference point was reached, as shown in Fig. 2. Subsequently, the stopwatch was stopped, and the duration of the cutting procedure was duly noted. Three dental diamond rotary instruments (White Z, KBlack, and KBlue) were used for crown sectioning. Each bur was used to section three crowns of the same ceramic type (zirconia or lithium disilicate), and the cutting time was recorded after each cut. The cutting efficiency was determined by measuring the time it took, in seconds, to successfully cut the crown.

Each diamond rotary bur was inspected under an environmental scanning electronic microscope (ESEM) (Thermo Fisher Scientific™ Inc., USA) before sectioning (control), and after first, second, and third crown sectioning to report characteristics related to diamond loss, wear, and morphology. For this purpose, an ESEM was used for surface analysis in all burs at x100 magnification and 30 kV accelerating voltage [40]. The image contrast was adjusted using a software program (Thermo Scientific™ Maps™ Software). Further, the elemental composition of the diamond rotary burs (Nickel and carbon) data were also obtained for the semi-quantitative chemical analysis of the diamond and metal matrix, using an energy dispersion spectrometer (EDS) and characteristics related to diamond loss and wear and morphology were observed in each condition [30].

The data acquired from the research were analyzed utilizing IBM SPSS software package version 20.0 (IBM Corp.). The normality of data was tested by the Shapiro-Wilk test. Quantitative data were expressed as mean and standard deviation. A three-way analysis of variance (ANOVA) was executed to investigate the impacts of bur type, material type, sectioning stage, and their interactions. One-way ANOVA was utilized to compare the various groups under scrutiny, followed by the Tukey post hoc test for pairwise comparisons. The statistical significance was defined at $p \leq 0.05$.

Results

The analysis showed a statistically significant impact of the material, the bur type, and the sectioning stage on the sectioning time efficiency, Table 1. The findings displayed a statistically significant difference among the groups ($p \leq 0.05$). Subsequently, a one-way ANOVA was conducted, followed by pairwise Tukey's post-hoc tests to ascertain the significance among the subgroups.

In terms of cutting cycle number impact on the cutting efficiency of the burs, the first bur use was statistically significantly more efficient than the second use to cut both zirconia and lithium disilicate crowns, irrespective of the type of the bur ($p \leq 0.05$). Likewise, the second-use burs were statistically significantly more efficient in crown cutting than the third-use burs, regardless of the bur or the material type ($p \leq 0.05$).

The first and second use of the bur is statistically significantly dependent on the type of the bur to cut zirconia crowns, white Z was the most time-efficient bur to section the zirconia crown, followed by super coarse KBlack, and the medium coarse KBlue comes last ($p \leq 0.05$), while the third use of the burs was non statistically significantly difference on the cutting time efficiency ($p > 0.05$), however, the bur preference is the same as the first and the second use.

In the first and the second use of burs to cut lithium disilicate crowns, white Z bur was the least time efficient to section the crown, followed by medium coarse Kblue bur, while KBlack bur was the most efficient to section the lithium disilicate crown ($p \leq 0.05$). The third use of the burs showed a statistically significant higher cutting efficiency of Kblack super coarse bur than white Z bur and Kblue burs ($p \leq 0.05$); however, white Z and the Kblue burs showed non statistically significant difference in the cutting time efficiency ($p > 0.05$).

In terms of the material type, the white Z bur cut more efficiently through lithium disilicate than zirconia crowns at the first and second use ($p \leq 0.05$), while the third use showed the same cutting efficiency for both crown materials, with non-statistical significant lower time for cutting through lithium disilicate ($p > 0.05$). However, KBlack and KBlue burs showed significantly higher time efficiency for cutting lithium disilicate crowns than zirconia crowns at the first, second, and third usage ($p \leq 0.05$).

The mean values and standard deviations of the sectioning time (in seconds) for the White Z, KBlack, and KBlue diamond burs on the two types of ceramic materials (zirconia and e.max) after each cutting stage are delineated in Table 2. These outcomes are visually represented in Fig. 3.

Table 1 Three-way ANOVA used to compare between bur type, material type and cutting stage for cutting time (second)

Source	Type III Sum of squares	df	Mean Square	F	*p*-value
Bur Type	9969.089	2	4984.544	473.466*	< 0.001*
Material type	19595.378	1	19595.378	1861.302*	< 0.001*
Cutting stage	40458.756	2	20229.378	1921.524*	< 0.001*
Bur type*Material type*Cutting stage	18862.600	12	1571.883	149.308*	< 0.001*

*: Statistically significant at $P \leq 0.05$

Table 2 Mean ± standard deviation of cutting times in second for different diamond bur on ceramic materials (Zirconia and E.max) after first, second and third cuts

Bur Type	Material type	1st cut	2nd cut	3rd cut
White Z	Zirconia	$130.4^{h} \pm 2.07$	$169.4^{d} \pm 3.05$	$191.2^{ab} \pm 4.12$
	E-max	$124.0^{h} \pm 3.16$	$154.4^{ef} \pm 2.41$	$189.0^{bc} \pm 3.39$
KBlack	Zirconia	$148.0^{fg} \pm 3.16$	$170.8^{d} \pm 2.59$	$193.0^{ab} \pm 1.92$
	E-max	$96.2^{j} \pm 2.59$	$110.0^{i} \pm 2.24$	$126.6^{h} \pm 5.94$
KBlue	Zirconia	$161.6^{e} \pm 3.05$	$182.2^{c} \pm 3.19$	$196.8^{a} \pm 2.59$
	E-max	$113.0^{i} \pm 4.30$	$144.4^{g} \pm 3.05$	$189.2^{bc} \pm 3.19$

($p < 0.001^{*}$)

Data was expressed using Mean ± SD. SD: Standard deviation *: Statistically significant at $p \leq 0.05$

(Means) with any Common letter and/or two letters from $^{(a-j)}$ are not significant

(Means) with totally Different letter and/or two letters from $^{(a-j)}$ are significant

Scanning electron microscopic (SEM) images of the diamond rotary instruments before and after the 1st, 2nd, and 3rd sections for zirconia and lithium disilicate crowns are displayed in Figs. 4 and 5, respectively. Before use, SEM images for the new diamond burs showed that all burs had a relatively homogeneous distribution of diamonds in the head. In comparison with the new ones, SEM images for the burs after each section showed significant differences, indicating more detachment of diamonds and wear with large particle size and shape with repeated sections. In some images, the deposition of the sectioning substrate adhered among the diamond grains could also be observed.

Regarding the White Z and KBlue burs after the sections, in comparison with the new ones, no difference in visible surface inspection was found after sectioning both zirconia and lithium disilicate crowns. SEM images showed no significant differences, indicating little detachment of diamonds and wear with small particle size and shape. In some images, the deposition of the cutting substrate adhered to the diamond grains could also be observed. Only images for KBlue appeared to have smaller diamond particles with wider spaces in between and less protruding from the embedding mass compared with White Z for both ceramic types. While KBlack burs after the sections, in comparison with before the section,

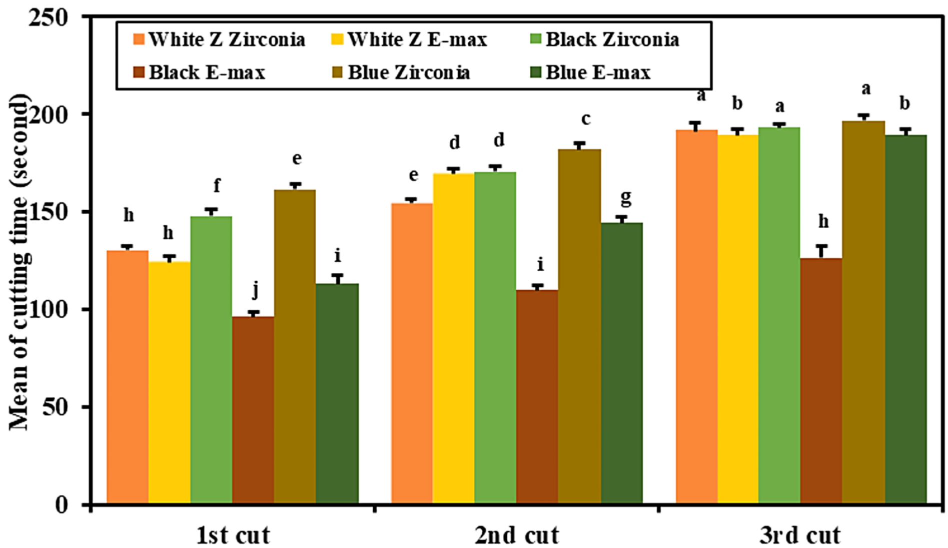

Fig. 3 Comparison between the different studied groups according to cutting time (second); different letters revealed significant differences

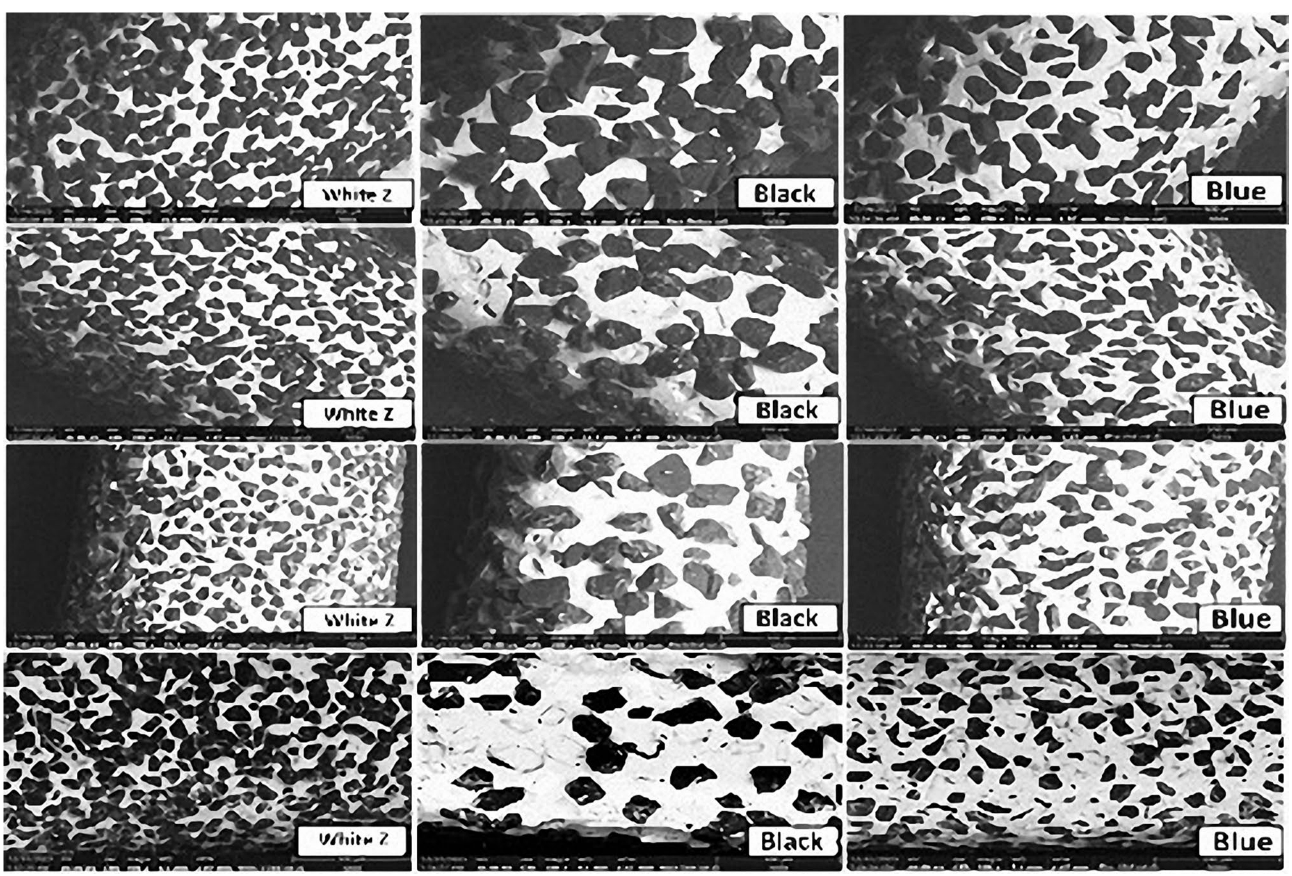

Fig. 4 Scanning electron microscope images of the surface of diamond rotary instruments for cutting zirconia restoration before use (1st row), after 1st cut (2nd row), after 2nd cut (3rd row), and after 3rd cut (4th row). Original magnification ×100

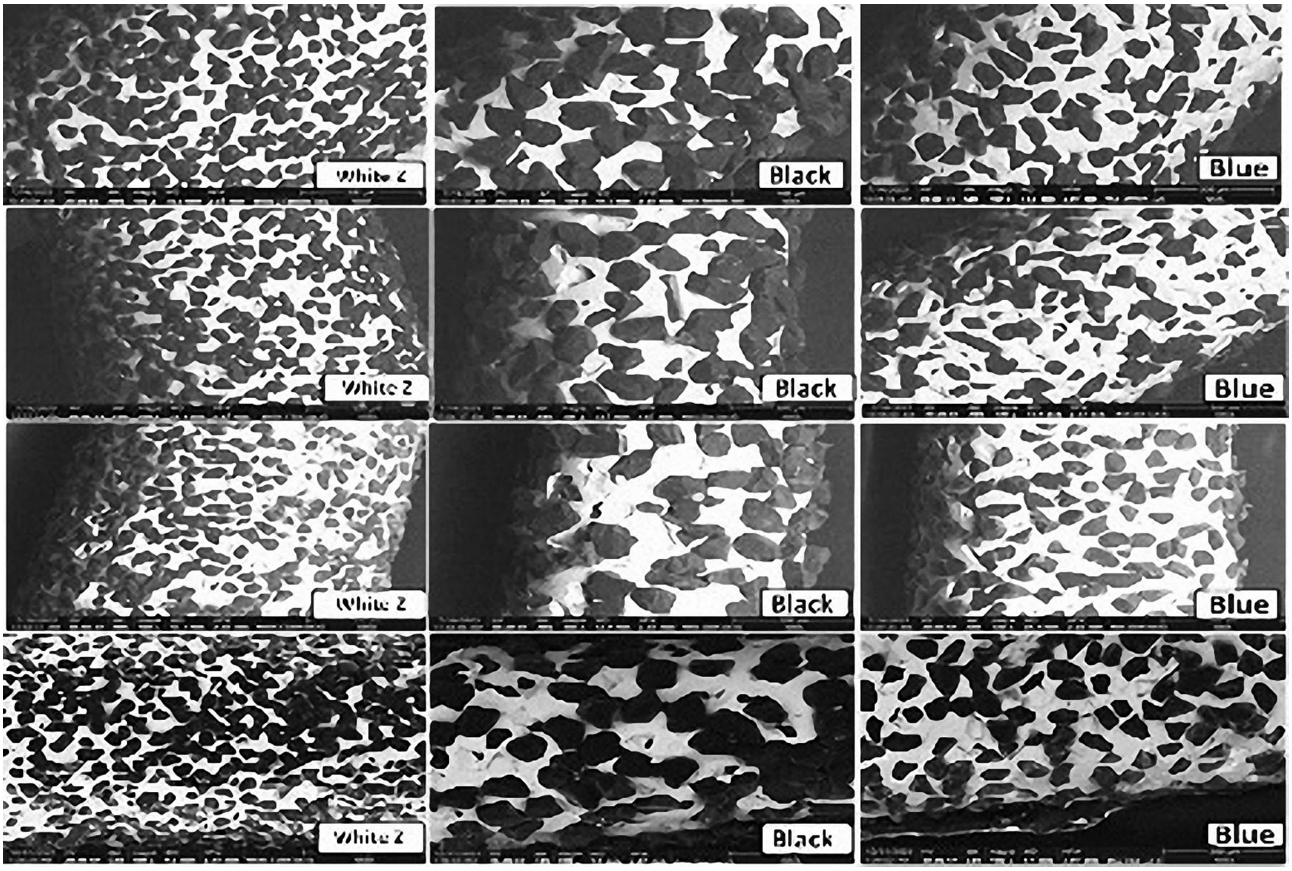

Fig. 5 Scanning electron microscope images of the surface of diamond rotary instruments for cutting E.max before use (1st row), after 1st cut (2nd row), after 2nd cut (3rd row), and after 3rd cut (4th row). Original magnification ×100

Table 3 Three-way ANOVA used to compare between bur type, material type and cutting stage for Carbon and Nickel

Element	Source	Type III Sum of squares	df	Mean Square	F	*p*-value
Carbon	Bur Type	661.365	2	330.682	2418.152*	< 0.001*
	Material type	1.850	1	1.850	13.529*	< 0.001*
	Cutting stage	19050.791	3	6350.264	46437.028*	< 0.001*
	Bur type*Material type*Cutting stag	1549.056	17	91.121	666.332*	< 0.001*
Nickel	Bur Type	1480.968	2	740.484	10254.829*	< 0.001*
	Material type	187.750	1	187.750	2600.117*	< 0.001*
	Cutting stage	10942.141	3	3647.380	50511.903*	< 0.001*
	Bur type*Material type*Cutting stage	1293.289	17	76.076	1053.560*	< 0.001*

their difference appeared to have medium to large diamond particles with wider spaces in between and protruding from the embedding mass for zirconia than lithium disilicate crowns in compared with White Z and KBlue for both ceramic types.

The semi-quantitative EDS analysis of all diamond rotary instruments had carbon and nickel elements as the main composition. It showed traces of other elements, such as oxygen. Three-way and one-way ANOVA comparisons between bur type, material type, and sectioning stage for carbon and nickel element composition (w %) of diamond particles are shown in Tables 3 and 4; Supplementary Figs. 1 and 2.

Discussion

This study aimed to ascertain the optimal grit size of different dental diamond rotary instruments and the time needed to section various ceramic crowns. The first hypothesis was partially rejected. For the first and second use of the white Z bur, as well as the super coarse KBlack_and medium coarse KBlue burs in all cuts, cutting through lithium disilicate crowns was more efficient than cutting through zirconia crowns. However, the white Z bur, on its third use, exhibited the same efficiency in cutting through lithium disilicate and zirconia crowns.

The second hypothesis was partially rejected; among the 9 comparisons, only the third time used white Z and

Table 4 Mean ± standard deviation of Carbon and Nickel element content (%) for different diamond bur on ceramic materials (Zirconia and E.max) before cut, after 1st, 2nd and 3rd cuts

Element	Bur Type	Material type	Before	1st cut	2nd cut	3rd cut
Carbon	White Z	Zirconia	$64.20^{b} \pm 0.16$	$60.22^{d} \pm 0.19$	$34.18^{n} \pm 0.26$	$30.72^{q} \pm 0.19$
		E-max	$64.20^{b} \pm 0.16$	$60.90^{cd} \pm 0.16$	$40.50^{i} \pm 0.22$	$35.74^{m} \pm 0.21$
	KBlack	Zirconia	$68.90^{a} \pm 0.22$	$54.40^{f} \pm 0.22$	$38.22^{k} \pm 0.19$	$25.64^{r} \pm 0.36$
		E-max	$68.90^{a} \pm 0.22$	$61.28^{c} \pm 0.19$	$41.70^{h} \pm 0.22$	$33.10^{o} \pm 0.22$
	KBlue	Zirconia	$55.70^{e} \pm 0.22$	$48.98^{g} \pm 1.49$	$36.92^{L} \pm 0.19$	$31.78^{p} \pm 0.19$
		E-max	$55.70^{e} \pm 0.22$	$49.30^{g} \pm 0.22$	$39.20^{j} \pm 0.16$	$34.00^{n} \pm 0.22$
	($p < 0.001^{*}$)					
Nickel	White Z	Zirconia	$35.50^{O} \pm 0.16$	$36.10^{O} \pm 0.16$	$50.50^{I} \pm 0.16$	$53.12^{G} \pm 0.26$
		E-max	$35.50^{O} \pm 0.16$	$38.54^{M} \pm 0.23$	$51.30^{H} \pm 0.22$	$55.10^{F} \pm 0.22$
	KBlack	Zirconia	$31.10^{P} \pm 0.22$	$43.90^{L} \pm 0.22$	$61.80^{C} \pm 0.22$	$68.12^{A} \pm 0.76$
		E-max	$31.10^{P} \pm 0.22$	$37.78^{N} \pm 0.19$	$52.68^{G} \pm 0.19$	$57.88^{E} \pm 0.19$
	KBlue	Zirconia	$44.30^{L} \pm 0.22$	$48.46^{J} \pm 0.24$	$59.30^{D} \pm 0.22$	$64.92^{B} \pm 0.36$
		E-max	$44.30^{L} \pm 0.22$	$45.44^{K} \pm 0.27$	$53.10^{G} \pm 0.22$	$64.38^{B} \pm 0.26$

($p < 0.001^{*}$)

Data was expressed using Mean ± SD. SD: Standard deviation *: Statistically significant at $p \leq 0.05$

Means with any Small Common letters $^{(a-r)}$ are not significant (or, in contrast, Means with totally Small Different letters $^{(a-r)}$ are significant) for carbon

Means with any Capital Common letters $^{(A-P)}$ are not significant (or, in contrast, Means with totally Capital Different letters $^{(A-P)}$ are significant) for Nickel

medium coarse KBlue revealed identical efficiency for cutting zirconia crowns; all the other 8 other comparisons showed different cutting time efficiency of different burs applied on different ceramic materials crowns. It was noted that traditional coarse-grit diamond rotary instruments (KBlack and KBlue) did not surpass diamond rotary instruments explicitly crafted for zirconia restoration removal (White Z). However, their effectiveness varied when eliminating lithium disilicate restorations, Table 2.

The third hypothesis was rejected; different cutting instruments with three uses on two different materials revealed different wear levels, represented by the deterioration of the diamond surface, which was characterized by a reduction in carbon and increased nickel contents. This was also obvious in the SEM representative images, which showed dramatic changes in the diamond distribution on the cutting burs after use, Figs. 4 and 5.

The efficiency of rotary instruments in cutting ceramic crowns is crucial in dental procedures. Previous studies evaluated cutting efficiency using laboratory non-anatomical specimens without oral condition simulation. However, the presented study was executed on an anatomical mandibular first molar crown with thermocycling simulation of the oral cavity, aiming to enhance the validity of the findings. The study design ensured standardization of variables such as handpiece performance, the single operator approach, coolant flow rate, and substrate used [21, 39]. Moreover, the SEM and EDS analysis revealed variations in the mean diamond compositions of the metal matrices of the burs. Such differences may provide a plausible explanation for the observed disparities in cutting efficiency [30].

Dental practitioners routinely face challenges during crown and restoration removal, it is essential to provide adequate data on the cutting efficiency of rotary instruments, facilitating better decision making, hence procedural flaws, saving time and effort, which will all reflect on the patient's comfortability. According to the findings of this study, every diamond bur displayed notably superior sectioning efficiency when employed for the sectioning of lithium disilicate crowns compared with zirconia crowns throughout every sectioning stage. These results agree with a prior laboratory study indicating that the abrasiveness of dental ceramic during a clinical adjustment is related to its properties, particularly the material's hardness, which explains the high time efficiency of cutting through lithium disilicate crowns compared to zirconia crowns [30]. Increased hardness may increase the friction between the bur and the sample, accelerating diamond grain pulling, cutting, and wear, resulting in shorter tool life [41]. Because in the present study, the zirconia material was 5YSZ, which has lower inherited mechanical properties and hardness than 3Y-TZP, the differences in the diamond burs integrity and SEM analysis among different crown materials sectioning were different but not very distinct in some subgroups.

The findings of the present study demonstrate statistically significant variations in sectioning time based on different types of burs, materials, and usage stages. However, it is important to consider the clinical implications of these differences. For instance, while there was a statistically significant difference of 61 seconds between the 3rd and 1st cuts of zirconia ceramic using the White Z bur, it may not substantially impact routine practice. In a clinical setting, the efficiency of sectioning can affect workflow, patient comfort, and overall procedural time.

Nevertheless, a 61-second difference, although measurable, is unlikely to significantly influence clinical outcomes or patient care during typical crown removal procedures. These findings suggest that while the efficiency of burs decreases with repeated use, the difference remains within an acceptable range for most clinical scenarios. Nonetheless, recognizing the efficiency trend is valuable for clinicians to make informed decisions about their burs and manage procedural times, especially when multiple crown sectioning is expected.

Apart from the ceramic material properties and irrespective of the bur type used, the performance of all burs deteriorates after repeated cutting cycles [41]. The super coarse KBlack diamond instruments in the current study exhibited high cutting efficiency during the initial section of lithium disilicate crowns compared to medium coarse KBlue burs and white Z burs and maintained this superiority throughout the study, albeit with a slower rate of efficiency declination. Previous laboratory studies on bars and block specimens support these results [42, 43]. It was assumed that the diamond particles undergo separation when sectioning is initiated. This separation leaves only limited diamond particle numbers surrounded by a significant amount of metal matrix, thereby reducing the cutting efficiency of the bur. Nevertheless, the diamond particle separation pattern could vary depending on the surrounding supportive metal matrix properties.

The reduction of cutting efficiency of the diamond burs after multiple uses on zirconia was relatively comparable to lithium disilicate, where all the burs have a cutting efficiency that ranges between 2 and 3.2 min for the entire crown sectioning. Regardless of the material, the burs efficiency curved down after each use. These findings varied from previous studies that concluded a more drastic reduction in diamond burs cutting efficiency on zirconia materials than glass-ceramic materials; this is due to the differences in the zirconia material nature applied; in the current study, the material was 5YSZ, which holds closer mechanical behavior and properties to lithium disilicate ceramic, while in the previous studies the tests were applied o high strength zirconia ceramic materials 3Y-TZP resulting in very high abrasiveness and were of the diamond instruments [44].

The SEM and EDS analysis of the new diamond burs 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. The results of the SEM analysis unveiled various discernible occurrences, such as grain pullover, grit fracture, and metal sub-structure impairment in the diamond bur, alongside abrasion and shearing of the diamond particles. Moreover, the analysis illustrated a gradual reduction in cutting efficiency because of debris accumulation and bur damage over time. Consequently, the research established a substantial relationship between the cutting efficacy of the subsequent and initial sections across all three burs. Eventually, almost all the burs revealed very close cutting duration irrespective of the bur or material type [42, 44, 45].

EDS analysis of the diamond burs after the 1st, 2nd, and 3rd sections showed different mean in compositions of the metal matrices of the burs by decreasing the percentage of carbon element and increasing nickel element percentage, besides the presence of some traces of oxygen element [46]. These results markedly represent the increasing detachment of large diamond particle sizes after repeated sections due to wear reflected by the reduction of carbon and the increased nickel elements of the bur after each use. To understand these chemical analyses, referring to the fabrication method of diamond dental instruments is essential. Diamond burs are manufactured by galvanic deposition of diamond powder (i.e. carbon is the ground element) into a metal matrix (Nickel). This fabrication technology has some inherent limitations because the diamond Particles can be dislodged, reducing the cutting efficiency.

The results of the presented study indicated that White Z burs demonstrated notably higher cutting efficiency of zirconia crowns than KBlack and KBlue. However, this difference did not reach high statistical significance during the third cutting cycle. The superior performance of White Z when cutting zirconia crowns could potentially be attributed to the proprietary technology employed by the manufacturers of zirconia cutting burs. This technology purportedly enhances the adhesion strength between the nickel plating on the bur and diamond particles, thereby improving the bur's durability and reducing diamond loss throughout the cutting procedure [25, 26].

In terms of cutting efficiency of lithium disilicate crowns, the conventional super coarse KBlack diamond bur exhibited considerably superior performance compared to the White Z and medium coarse KBlue diamond burs throughout all cutting phases. These results confirm a previously published laboratory study on non-anatomical specimens, indicating that cutting efficiency rises with larger diamond particle dimensions [27].

The implications of these findings hold notable clinical significance by offering valuable insights to practitioners in the selection of diamond burs with superior cutting efficiency. Opting for higher cutting efficiency burs enables clinicians to effectively mitigate complications, reduce patient discomfort, and save time and costs of ceramic restoration removal. Considering that the cutting efficiency of diamond burs decreases progressively with every cutting cycle.

The present study has certain limitations. Firstly, it only focused on two types of monolithic ceramic materials and did not consider the underlying structure of the natural tooth. Additionally, the cutting cycles were performed on dummy heads, which do not fully replicate the clinical situation in the patient's mouth. It is important to recognize that in a clinical setting, the sterilization procedures following each use of a bur among patients could affect the cutting effectiveness of these rotary instruments. Research investigating the impact of disinfection procedures on the cutting efficiency of diamond burs has produced inconsistent results. Bae et al. [47] concluded that repeated disinfection does not negatively affect cutting efficiency. Similarly, Gureckis et al. [48] found that the cutting efficiency of diamond burs remains unchanged even after undergoing 10 consecutive disinfection cycles, including autoclaving. In contrast, a recent study by Gonzaga et al. [30] specifically identified autoclaving as a factor that negatively impacts the cutting efficiency of the diamond burs under investigation.

Conclusions

Within the limitations of this study, the following conclusions can be drawn:

1. All tested diamond burs showed cutting efficiency that ranged between 1.5 and 3.2 min related to the bur used but mostly adversely correlated to the number of cutting cycles, where all diamond burs exhibited low cutting efficiency after repeated use.
2. White Z bur designed specifically for sectioning zirconia exhibits superior performance and durability in sectioning zirconia dental crowns compared with conventional diamond rotary burs.
3. Conventional super coarse KBlack burs are more effective in cutting lithium disilicate crowns than zirconia-cutting burs and conventional medium coarse KBlue diamond burs.
4. Cutting zirconia ceramic crowns was relatively longer than cutting lithium disilicate crowns, particularly for super coarse diamond burs, while white Z and medium coarse burs showed comparable efficiency for cutting zirconia and lithium disilicate crowns at the third use.

Abbreviations

CAD	Computer-aided design
CAD/CAM	Computer-aided design/computer-aided manufacturing
EDS	Energy dispersion spectrometer
SEM	Scanning electron microscopic

Supplementary Information

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Supplementary Material 1

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Author contributions

SB, RHB and MHA, AAA contributed to the conception and design of the study, collection of data, interpretation of the analyzed data; MHA, MAA and AYA checked the data and results, writing the manuscript, revised and reviewed the draft manuscript; All authors read and approved the manuscript.

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Data availability

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Competing interests

The authors declare no competing interests.

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