open access scientific journal

Volume 26 N º 01 - 2023 | Special Edition

BDS Brazilian Dental Science

25th Jubilee

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ORIGINAL ARTICLE DOI: https://doi.org/10.4322/bds.2023.e3706

Mechanical behavior of different machinable ceramic crowns using vertical and horizontal preparations: an in-vitro study

Comportamento mecânico de diferentes coroas cerâmicas usináveis usando preparos verticais e horizontais: um estudo *in vitro*

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How to cite: Nouh I, Rafla N, Ebeid K. Mechanical behavior of different machinable ceramic crowns using vertical and horizontal preparations: an in-vitro study. Braz. Dent. Sci. 2023;26(1):e3706. https://doi.org/10.4322/bds.2023.e3706

ABSTRACT

Objective: the aim of this study was to compare the mechanical behavior of different ceramics when used in thin vertical preparations versus traditional horizontal preparation. **Material and Methods:** two stainless-steel dies were milled to simulate a minimally invasive vertical preparation (VP) and a traditional horizontal preparation (HP) for an all-ceramic crown of a maxillary first premolar. The stainless-steel dies were duplicated using epoxy resin. Eighty monolithic crowns were milled and divided into 2 groups according to preparation design. Each design group was subdivided into 4 sub-groups according to material (n=10): IPS e.max CAD (lithium disilicate), Bruxzir shaded zirconia (full contour zirconia), CeraSmart (resin nanoceramic) and CEREC Tessera (advanced lithium disilicate). The crowns were cemented on their relevant epoxy resin dies using self-adhesive resin cement. All specimens were subjected to 15,000 thermocycles and then loaded to fracture in a universal testing machine. Data were analyzed using two-way ANOVA and Tukey pair wise comparison test. **Results:** the fracture resistance mean values of the VP (1344 + 118 N) was significantly lower than the HP design (1646 + 191 N). Ceramic crowns made of full contour zirconia had higher fracture resistance mean values (2842 + 380 N) than advanced lithium disilicate (1272 + 125 N) followed by lithium disilicate crowns (983 + 52 N) and resin nanoceramic (882 + 61 N). **Conclusion:** both vertical and horizontal preparations, regardless the different ceramic materials, showed clinically acceptable fracture resistance values.

KEYWORDS

Dental crown; Prosthodontics; Zirconia; Lithium disilicate; Hybrid ceramics.

RESUMO

Objetivo: o objetivo deste estudo foi comparar o comportamento mecânico de diferentes cerâmicas quando utilizadas em preparos verticais finos ou preparos horizontais tradicionais. **Material e Métodos:** dois modelos de aço inoxidável foram fresados para simular um preparo vertical minimamente invasivo (PV) e um preparo horizontal tradicional (PH) para uma coroa totalmente em cerâmica de um primeiro pré-molar superior. As matrizes de aço inoxidável foram duplicadas usando resina epóxi. Oitenta coroas monolíticas foram fresadas e divididas em 2 grupos de acordo com o desenho do preparo. Cada grupo foi subdividido em 4 subgrupos de acordo com o material (n=10): IPS e.max CAD (dissilicato de lítio), zircônia Bruxzir (zircônia de contorno total), CeraSmart (resina nanocerâmica) e CEREC Tessera (dissilicato de lítio avançado). As coroas foram cimentadas em suas respectivas matrizes de resina epóxi usando cimento resinoso autoadesivo. Todos os espécimes foram submetidos a 15.000 ciclos térmicos e então carregados até a fratura em uma máquina de teste universal. Os dados foram analisados usando ANOVA com dois fatores e teste de comparação por pares de Tukey. **Resultados:** os valores médios de resistência à fratura do PV (1344 + 118 N) foram significativamente menores do que PH (1646 + 191 N). As coroas de cerâmica feitas de zircônia de contorno total apresentaram maiores valores médios de resistência à fratura (2842 + 380 N) do que dissilicato de lítio avançado (1272 + 125 N), seguido por coroas de dissilicato de lítio (983 + 52 N) e resina nanocerâmica (882 + 61 N). **Conclusão:** preparos verticais e horizontais, independentemente dos diferentes materiais cerâmicos, apresentaram valores de resistência à fratura clinicamente aceitáveis.

PALAVRAS-CHAVE

Coroa dental; Prótese dentária; Zircônia; Dissilicato de lítio; Cerâmica híbrida.

INTRODUCTION

The conservation of tooth structure has become the primary goal of restorative dentistry. However, combining maximum conservation with minimally invasive preparations without compromising esthetics and strength of the final restoration has always been challenging [1,2].

Preserving the tooth structure through adequate preparation technique reduces the crack propagation, redistributes stresses and subsequently increases the teeth durability [3].

The clinician usually prepares the abutment to receive the fixed partial denture ((FPD) by establishing a finish line on which the restoration rests. Finish lines are classified into vertical and horizontal, where the latter could be supragingival or subgingival which has been shown to cause more gingival inflammation. Horizontal finish lines consist of knife or feather-edge margins [4].

The Biologically Oriented Preparation Technique (BOPT) has been recently suggested as a minimally invasive type of preparation that uses a vertical finish line and can be adopted in many clinical situations. It is commonly used for periodontally affected teeth with gingival recession where conservation is a priority for long-term success of the abutment. This technique prepares the teeth to receive the restoration with no finish line; hence removing the original Cement Enamel Junction (CEJ) and allowing a newly created Prosthetic Cement Enamel Junction (PCEJ) [5,6].

The tooth then receives an interim restoration allowing gingival adaptation and thickening which a crucial phase in the BOPT, then the final restoration is manufactured, where the marginal gap between the FPD and the tooth in conventional methods are eliminated [7].

The BOPT has been under study to determine the long-term success of the restorations and the effect of lack of finish line on the periodontal health. Studies have recently shown significant success of anterior and posterior FPDs with abutment teeth having good marginal and gingival [5,8,9].

For the success of a final restoration, it is necessary to meet three main criteria; marginal stability, fracture strength and esthetics [10,11]. With the BOPT is crucial that the choose restorative material can be used in thin thicknesses yet without compromising its mechanical properties. Lithium Disilicates provide adequate strength o f 300-400 MPa combined with adequate esthetics and high bonding properties, while monolithic Zirconia has higher flexural strength of 900-1200 MPa promoting its use in very thin preparations. These two materials have been evaluated with feather edge finish lines and showed acceptable results; however, they have high wear on the opposing dentition [9,12].

Resin Nano ceramics provide acceptable esthetic, has higher modulus of resilience and higher flexural strength in comparison to conventional feldspathic CAD/CAM ceramics. Moreover, these Resin Ceramics are easily polished with no need for extra time for crystallization [13,14]. Advanced Lithium Disilicates are novel ceramics introduced to the market using different methods of fabrication where the addition of Virgilite crystals increases its flexural strength >700 MPa. How their properties are compared to conventional lithium disilicates is still unclear. They can be used to restore single crown, partial restorations and FPDs replacing a missing tooth up-to the second premolar with no need for further crystallization [15].

MATERIAL AND METHODS

Two standardized stainless-steel dies were prepared by a milling machine (Gerossa, Cairo, Egypt) to simulate different crown preparation of a maxillary first premolar: vertical preparation with 0.1 mm feather-edge margin (VP) or horizontal preparation with 1 mm radial shoulder (HP) as shown in Figure 1. The stainless-steel dies were machined with a height of 5.5 mm, a diameter of

7.5 mm, a 12° total occlusal convergence angle and a flat occlusal surface [16]. A 45° occlusal bevel was prepared at the occluso-axial line angle on the buccal side for exact repositioning of the crowns during seating and cementation and to act as an anti-rotational feature.

Each stainless-steel die was duplicated into an epoxy resin die using a non-shrink epoxy resin material (Kempoxy 150 transparent, CMB, Cairo, Egypt). 40 epoxy resin dies were fabricated from each design. Each epoxy resin die was scanned using CEREC Omnicam intraoral scanner (Dentsply Sirona, Bensheim, Germany). Eighty full contour monolithic ceramic crowns were designed and milled using CEREC CAD/CAM system (CEREC MCXL, Dentsply Sirona, Germany) and divided into two groups (n=40)

Figure 1 - Showing vertical preparation of 0.1 mm feather-edge design on the left and horizontal 1 mm radial shoulder on the right.

according to preparation design (VP or HP). Each group was sub-divided into four sub-groups according to ceramic material: (L) lithium disilicate (IPS e.max CAD, Ivoclar Vivadent, Schaan, Liechtenstein), (Z) full contour zirconia (Bruxzir shaded, Glidewell, USA), (C) resin nano ceramic (CersaSmart, GC,Tokyo, Japan) and (T) advanced lithium disilicate (CEREC Tessera, Dentsply Sirona, Bensheim, Germany) (Figure 2). The monolithic crowns were standardized in the inlab software (CEREC software version v3.8, Densply Sirona, Bensheim, Germany). After milling, each crown was checked on its relevant epoxy resin die and given a serial number. L crowns were crystallized and glazed in a combination firing cycle using IPS e.max CAD Crystall/Glaze Paste (Ivoclar Vivadent, Schaan, Liechtenstein), Z crowns were sintered in the infire HTC speed furnace (Dentsply Sirona) for 90 minutes at a sintering temperature of 1540°C, C crowns were only polished and T crowns were glazed and sintered in CEREC speedfire (Dentsply Sirona) at 760°C. The crowns were then cleaned in ultrasonic water bath to remove any residues and their fit on their relevant epoxy resin dies was checked again (Figure 2).

The inner surfaces of the crowns were treated prior to cementation according to the manufacturer's recommendations of each ceramic material and cement type. L groups; were etched using 9% hydrofluoric acid gel (Porcelain etch, Ultradent Products, United States) for 20 seconds, then rinsed thoroughly and dried with oil free air. The surfaces were then silanized by a primer (Porcelain Silane, Ultradent Products, United States) and left to react for 60 seconds. *Z Group;* was sandblasted (Renfert basic classic sandblaster, Hilzingen, Germany) with 50 μm Al_2O_3 at 1 bar at 10 mm distance. C group: T Group

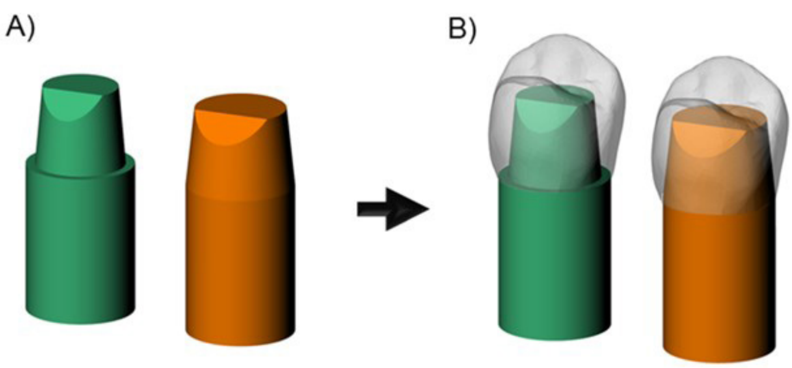

Figure 2 - (A) Illustration of epoxy resin dies with 2 preparations, (B) Illustration of dies with crowns seated in place.

was etched using 5% hydrofluoric acid gel (IPS Ceramic Etching Gel, Ivoclar Vivadent, Germany) for 30 seconds, then rinsed thoroughly and dried with oil free air. The surfaces were then silanized by a primer (Porcelain Silane, Ultradent Products, United States).

Each crown was cemented using self-adhesive resin cement (RelyX Unicem Aplicap Capsules, 3M ESPE, Minnesota, United States). Capsules were activated and mixed in the mixing device for 10 seconds according to manufacturer's instructions. The cement was applied to the fitting surface of the crowns, lightly thinned with air to ensure its unform distribution. The crowns were seated on their relevant epoxy resin dies by static finger pressure then axially loaded with a 5 kg load using a specially designed loading device and curing was done for 20 seconds on the buccal and palatal surface using a light curing device (Elipar Deep Cure, 3M ESPE, Minnesota, USA). The crowns were left under the static load for 10 minutes to ensure cement setting. All the cemented specimens were left undisturbed for 1 h and then stored in distilled deionized water for 24 h prior to testing. Specimens were then subjected to 15,000 thermocycles, temperature fluctuations were 5°C to 55°C with a 60-seconds dwell time at each temperature.

Specimens were then subsequently loaded to fracture in a universal testing machine (LRX-plus; Llyod instruments Ltd., Fareham, UK) using a stainless-steel bar with a 3 mm diameter ball end centralized along the long axis of the samples. 0.3 mm thick tin foil was placed between the loading stamp and crowns to achieve a homogenous stress distribution. Load was applied using a preload of 5 N and a cross-head speed of 1mm/min until failure. Failure was determined when a sharp drop in the load to displacement curve took place or an audible sound was heard or when the curve went from straight to an irregular pattern. Data was recorded and analyzed with controlling computer software (Nexygen-MT 4.5.1; Llyod instruments, Ametek, West Sussex, UK). The collected data was revised, coded and tabulated using Statistical Package for Social Sciences (SPSS) version 20 and Microsoft Office 2013 (Excel). Data was presented and suitable analysis was done according to the type of data obtained for each parameter. Shapiro-Wilk test was used to assess data normality and data was assumed normally distributed. Two-Way ANOVA test was used to examine effect of preparation design and material and on the fracture resistance. P-value is the level of significance, if $P > 0.05$: Nonsignificant (NS), $P \leq 0.05$: Significant (S).

RESULTS

Two-way ANOVA revealed a significant influence of the preparation design and ceramic material on the fracture resistance of monolithic crowns. The fracture resistance of the VP design (1344 + 118 N) was significantly lower (p=0.0153) than the HP design (1646 + 191 N. regardless of the ceramic material. Within the vertical preparation design, Tukey's post hoc test showed that translucent zirconia had higher fracture resistance mean values (2708 + 266 N) than advanced lithium disilicate (1112 + 119 N) followed by lithium disilicate crowns (869 + 51 N) and resin nanoceramic (687 + 36 N) and the differences were statistically significant (p<0.001). However, within the horizontal preparations, Tukey's HSD showed that translucent zirconia had significantly higher fracture resistance mean values (2977 + 495 N) than advanced lithium disilicate (1434 + 132 N) and statistically significantly higher than lithium disilicate (1098 + 53 N) and Resin Nano ceramic (1078 + 87 N) which were not statistically different.

DISCUSSION

Being minimally invasive while respecting biology and obtaining high esthetics requires materials that has both optimum esthetic and high mechanical properties when used in minimum thicknesses [17,18]. The increasing popularity of the BOPT concept in the recent years raised a question whether different machinable ceramic materials available in the market can be used in minimum thickness in vertical preparations. Hence, this in-vitro study aimed to test the mechanical behavior of ceramic materials from different compositions; resin nanoceramic, lithium disilicate, advance lithium disilicate and zirconia in vertical preparation designs and compare it to the gold standard horizontal preparations.

Horizontal preparation as radial shoulder and deep chamfer finish line preparation with a thickness of 1-1.5 mm all around at the cervical margin is the gold standard for all-ceramic crown preparations and the one recommended by the manufacturers of all ceramic material [19,20]. Tooth preparations are based on maximum preservation of dental substance, especially in the cervical area where the pulp preparation distance is of vital importance, both for the strength of the abutment and to reduce the onset of pulp complications. The increased mechanical properties of machinable ceramics allowed clinicians to consider using minimal preparations as the vertical preparations. However, the literature contains an abundant amount of criticism of such vertical preparations, mainly because of the presence of an over-contoured restorations and the consequent fragility of the crown, determined by the limited thickness of the restoration in the cervical area, also difficulty in processing accuracy and clinical chipping fractures [21]. However, recently the literature has been recommending this minimal preparation for conservation of tooth structure and better health for the gingival tissues [1,22].

In this in-vitro study, our results showed that fracture resistance values of vertical preparations were significantly lower than horizontal preparations. This could be due to better load distribution on the 1 mm horizontal margin, the presence of a definite margin which was capable of counteracting forces directed to it and more material thickness. However, the mean fracture loads for the VP (1432 + 809 N) although it was less than HP, it still exceeded the maximum chewing forces reported in the literature in the posterior region (300 – 850 N) [23]. Accordingly, this means that vertical preparation design could be an alternative to the less conservative chamfer and shoulder margin designs and can be used in certain clinical situations, such as severely damaged teeth, endodontically treated teeth, periodontally affected teeth and implant supported restorations where margin needs to be placed deep subgingival following the BOPT concept [24,25].

Our results agreed with several studies [19,26-28], which reported that a 1 mm deep shoulder finishing line with a rounded internal line angle has better fracture strength for all ceramic crowns and provide more even stress distribution than other preparation design. However, other studies reported good success rates for vertical preparations [29-35] as Reich et al. [34] who reported knife edge finish lines had 38% higher fracture load values than chamfer finish lines [34].

Monolithic zirconia crowns showed the highest fracture resistance mean values regardless the preparation design. This could be attributed to the superior mechanical properties of zirconia restorations, especially transformation toughening and resistance to crack propagation in comparison to silica-based ceramics; lithium disilicate and advanced lithium disilicate and resin based nanoceramic. Lithium disilicates however, had higher fracture resistance mean values than the posterior bite force and has well documented long term success when used in feather edge margin designs [12,36-39]. This justifies the possible use of advanced lithium disilicate in vertical preparations as they have shown higher fracture resistance than LD. This is due to its unique microstructure of 0.5 μm long lithium disilicate crystals embedded in a glassy matrix together with 0.2–0.3 μm platelet like lithium alumino silicate crystals ($Li0.5Al0.5Si2.5O6$), known as virgilite [15]. As for resin nanoceramic, they had the lowest fracture mean values due to their weaker resinous matrix [14].

Although vertical preparations provide more conservative preparations and biological response to tissues as proven by the literature. A recent study in the US in 2018, showed that most dentists still prefer chamfer/heavy chamfer margin designs, followed by shoulder preparations [40]. This reflects on the lack of sufficient data awareness and education of possible other techniques that can be used by dentist in different situations.

The choice of machinable ceramic to be used not only should depend on its mechanical and esthetic properties but also their biological compatibility and soft tissue response. Zirconia has an advantage in terms of biological properties with soft tissues as it encourages fibroblasts cell attachment and has a low surface energy and hence has low bacterial colonization on its surface when used as a polished surface in the subgingival areas [41,42]. This makes it from the authors opinion one of the most recommended materials in the subgingival areas of the BOPT. Additional laboratory and clinical studies are needed to study the effect of using different machinable ceramics on the soft tissue response and material survival in BOPT.

CONCLUSION

Within the limitations of this study the following can be concluded:

1- The use of vertical preparation is a successful type of preparation design which can preserve more tooth structure than traditional horizontal preparations while providing good biological seal with the surrounding soft tissue.

2- All tested ceramic materials showed fracture resistance within the clinically acceptable range.

Author's Contributions

IN: Conceptualization. NR: Methodology. IN, KE: Writing – Original Draft Preparation. NR: Writing – Review & Editing. KE: Supervision.

Conflict of Interest

The authors declare no conflict of interest.

Funding

No funding was received.

Regulatory Statement

Authors declare that no ethical committee approvals were needed for this study.

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Date submitted: 2022 Nov 22
Accept submission: 2022 Nov 30