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Original Article

Fracture Resistance of 3-Unit Monolithic ZrO_2 Ceramics FPDs with Different Preparation Designs of the Distal Abutment – an In-Vitro Study

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Abstract

Introduction: Masticatory pressure increases in the distal areas of the dentition. This should be considered when restoring partially edentulous patients with a metal-free fixed partial denture (FPD). An alternative abutment preparation design can be used in order to increase the materials' volume in the most fracture-prone "connector area" of an FPD. The increased size of the connection might positively influence the constructions' mechanical durability, thereby increasing its success and survivability.

Aim: The aim of the present study was to investigate the influence of two preparation designs of the distal abutment on the fracture resistance of three-unit, monolithic, ZrO_2 FPDs.

Materials and methods: 3D printed replicas of a partially edentulous mandibular segment and a ZrO_2, milled in full-contour, three-unit FPDs were used for this investigation. Two experimental groups (n=10) were defined based on the preparation design of the distal abutment tooth – classical shoulder preparation 0.8 mm deep, and endocrown preparation with a 2-mm retention cavity. The bridge – mandibular segment replica assembly was done with relyXU200(3M ESPE, USA), light-cured for 10 seconds per side with D-light Duo (GC, Europe). After cementation the test specimens were subjected to loading in a universal testing machine Zwick (Zwick-Roell Group, Germany). Statistical analysis was performed using R and includes descriptive statistics, t-test for quantitative and chi-squared test for qualitative variables.

Results: The results showed no difference between the two studied groups in the maximum force required to fracture the test specimens [$t=-1.8088$ (17.39), p-value=0.087; $P>0.05$]. 95% of the fracture lines were located in the distal connector.

Conclusions: Within the limitations of this study, it can be concluded that both tested preparation designs show similar results in terms of the load required to fracture the test specimens. Furthermore, it is confirmed that the distal connector is the weakest area of an all-ceramic 3-unit FPD in the posterior area.

Keywords

3-unit bridge, distal connector, fracture resistance, zirconium dioxide ceramics, endocrown

INTRODUCTION

Improvements in the mechanical properties and introduction of new ceramic materials in recent years have led to the extensive use of metal-free restorations, not only as partial and full crowns but also as short-span fixed partial dentures (FPDs).[1] Studies have demonstrated that these dentures have a clinical performance similar to that of the metal-ceramic restorations when used in the anterior region of the dentition.[2] However, stress resulting from mastication in the distal area of dental arches is greater[3], which places an emphasis on the mechanical properties of the materials used to manufacture posterior restorations. Monolithic zirconium dioxide crowns show similar fracture resistance when compared to metal-ceramic restorations, especially in cases with limited material thickness. They are superior in this regard to veneered zirconium dioxide ceramics as well as other all-ceramic restorations.[4,5] Furthermore, the incidence of chipping, which is the main failure mode in the aforementioned restoration types, is greatly reduced due to the uniformity of full-contour zirconium dioxide ceramics.[4]

An important factor influencing the fracture resistance of FPDs, besides the choice of appropriate material, is the design of the restoration.[6] Different studies demonstrate that the weakest link in bridge restorations is the connector area between the pontic and the retainer.[7,8] This might be in part due to morphological constrains – the height of the clinical crowns of the teeth distally from the canines normally decreases. Also, an adequate space for the dental papilla, as well as for occlusal embrasure is required, because of biological and aesthetic reasons. This leads to reduced connector area, which in turn weakens the entire restoration.[9] Studies published by Toshihiko Murase et al., Yasushi Ogino et al., and Nuno Calha et al. show that the geometry of the cross section is an important feature for the fracture resistance of FPDs.[10-12] Furthermore, the shape and cross-section area of the connector as well as the radius of the gingival embrasure have been demonstrated to be the key design elements to be considered.[13] Although the depth of the occlusal embrasure plays a significant role in the height of the connector area several authors note that in experimental conditions the initiation of the crack starts from the gingival portion and suggest that the radius of curvature may be equally or even more important.[14,15]

There is an interdependence between the choice of material, construction and tooth-preparation design.[16,17] An important aspect in planning a bridge restoration is the vitality of the abutment teeth. A controversy exists in choosing the best approach for restoration of endodontically treated molars, especially when they are considered as abutments for fixed partial dentures. Different studies suggest that posts and cores can improve the retention of full coverage crowns but may weaken the residual dental tissues, thus inducing a fracture.[18] An alternative design for preparation in which the restoration is designed as "mono-block" is the endocrown.[19] This type of construction is more favorable in terms of mechanical properties, stress distribution, tissue preservation, clinical success as well as clinical and laboratory processing time.[20] However, all present studies focus on single crown restorations.

AIM

The aim of the current study was to investigate the influence of two preparation designs of the distal abutment on the fracture resistance of three-unit monolithic FPDs manufactured from ZrO_2 ceramics.

MATERIALS AND METHODS

Design of a dental arch defect with one missing premolar

A dental arch defect with one missing tooth – the lower right second premolar, was recreated on an A3 dental study model (Frasaco[GmbH], Germany) with artificial teeth – Typodont A3 (Frasaco[GmbH], Germany). The distal area of the lower jaw was selected due to the short clinical crowns and adequate shape and position of the pulp chamber. The lower right second premolar was chosen since it has an occlusal surface with three cusps, which allows a 3-point contact and identical position of the loading element in the subsequent mechanical tests.

Specimen design and manufacturing

Classical preparation and FPD design

A pre-scan with Trios (3Shape, Denmark) of the lower right quadrant (47, 46, 45, 44, and 43) of the mandible was performed. Tooth 45 was removed and the artificial alveola in the model was filled with inert material Zetaplus (Zhermack, Italy) in order to simulate an edentulous area. The teeth adjacent to the defect (44 and 46) were prepared with 0.8 mm shoulder with a rounded inner angle. The occlusal reduction was 1.5 mm following the V-prep concept. The convergence angle was set at 6 degrees **(Fig. 1)**.

A scan of the prepared teeth and the adjacent structures was performed with an intraoral scanner Trios (3Shape, Denmark). The morphology of the obtained pre-scan was used to design the shape of the final restoration **(Fig. 2)**.

The distal connector was designed with a horizontally oriented elliptical shape with a cross section of 9 mm^2. The mesial connector has an identical area but a circular cross-section due to morphological constrains **(Fig. 3)**. A total of 10 specimens were fabricated employing this design and were used as the control group (C-group) in the study.

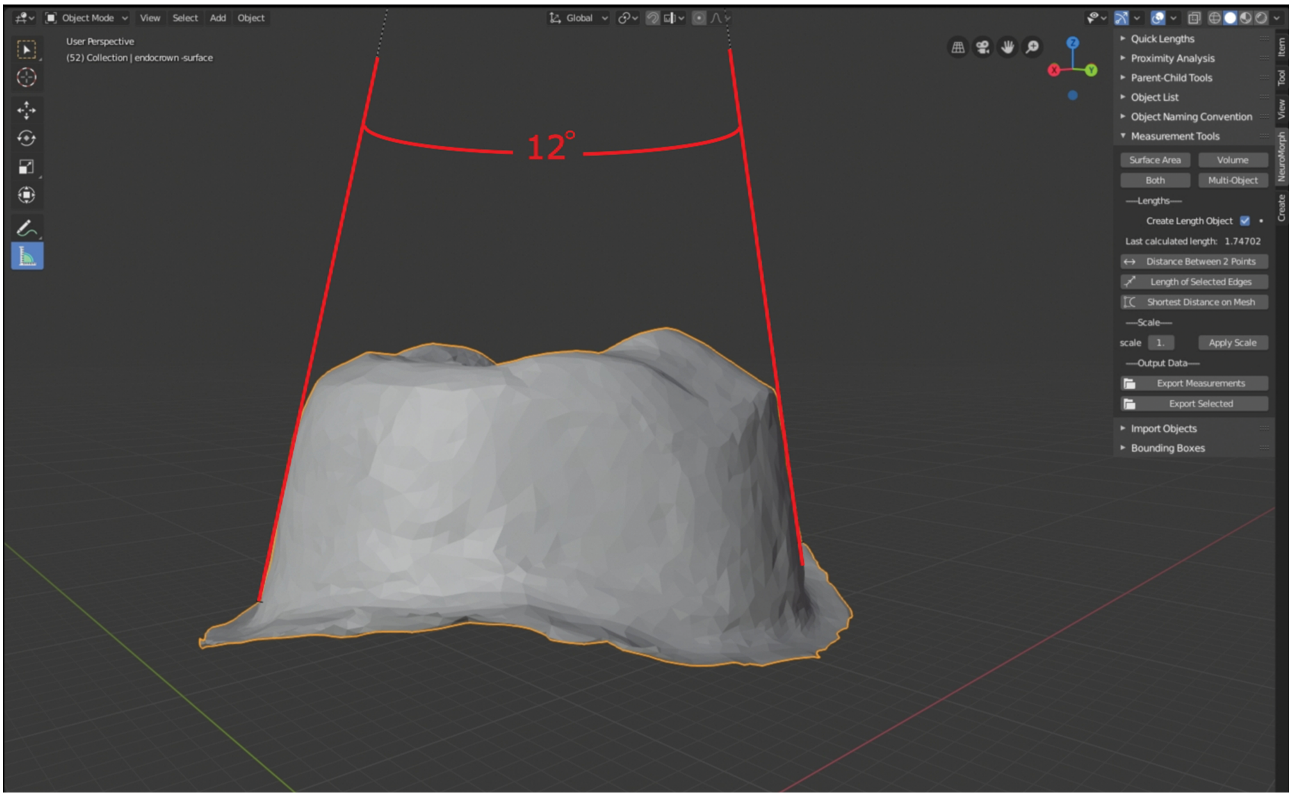

Figure 1. Total occlusal convergence angle.

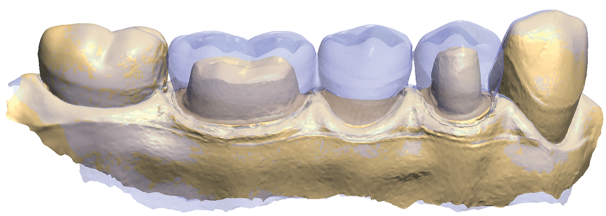

Figure 2. Pre-scan of the phantom model used for the final morphology of the FPD.

Endocrown preparation and FPD design

One of the finished bridge restorations from the classical preparation group was fitted on the same study model and a second pre-scan was performed in order to reproduce the exact morphology and connector's shape and area for the endocrown retained FPD **(Fig. 4)**.

An alternative preparation design of the distal tooth was made, which included a retention cavity in the area of the pulp chamber. The depth was set at 2 mm, and the remaining axial walls were more than 1.50 mm in width **(Fig. 5)**. All other preparation features, for both abutment teeth, were preserved from the classical design. The second pre-scan was used to create identical to the classical design FPD morphology, including the connector areas.

The only differences in the design were the intaglio surface of the distal crowns due to its alternative preparation **(Fig. 6)**. A total of 10 specimens were fabricated employing the endocrown design and were used as the endocrown group (E-group) in the study.

Fabrication of FPDs, edentulous replica (base) and specimen assembly

A total of 20 FPD full-contour restorations were milled with a VHF CAM5-S2 Impression (VHF, Germany) milling machine, using ZrO_2 based ceramics DD Bio ZX^2 (Dental Direkt GmbH, Germany). The sintering process was performed following the manufacturer's instructions for the selected material with a ceramic furnace Vita Zircomat6000MS (Vita Zahnfabrik GmbH, Germany). The protocol included shade application with DD Bio ZX^2 – monolith zero (Dental Direkt GmbH, Germany) and glazing white Vita Akzent – glaze Akz25 (VITA Zahnfabrik GmbH, Germany).

In order to perform the 3-point fracture resistance test, a supporting structure was needed. The latter was created using the virtual models obtained for both preparation designs via the Model builder module in 3Shape Dental System (3Shape, Denmark). The vertical thickness of the base was set at 10 mm. Both models were printed using the Form2 3D printer (Formlabs, USA) from an engineering resin – Tough resin (Formlabs, USA). The manufactured FPD and base are shown in **Fig. 6**.

Prior to the assembly procedure, the fit of the FPD's to the printed base was independently assessed by two blinded investigators (V.H. and A.V.). The evaluation procedure

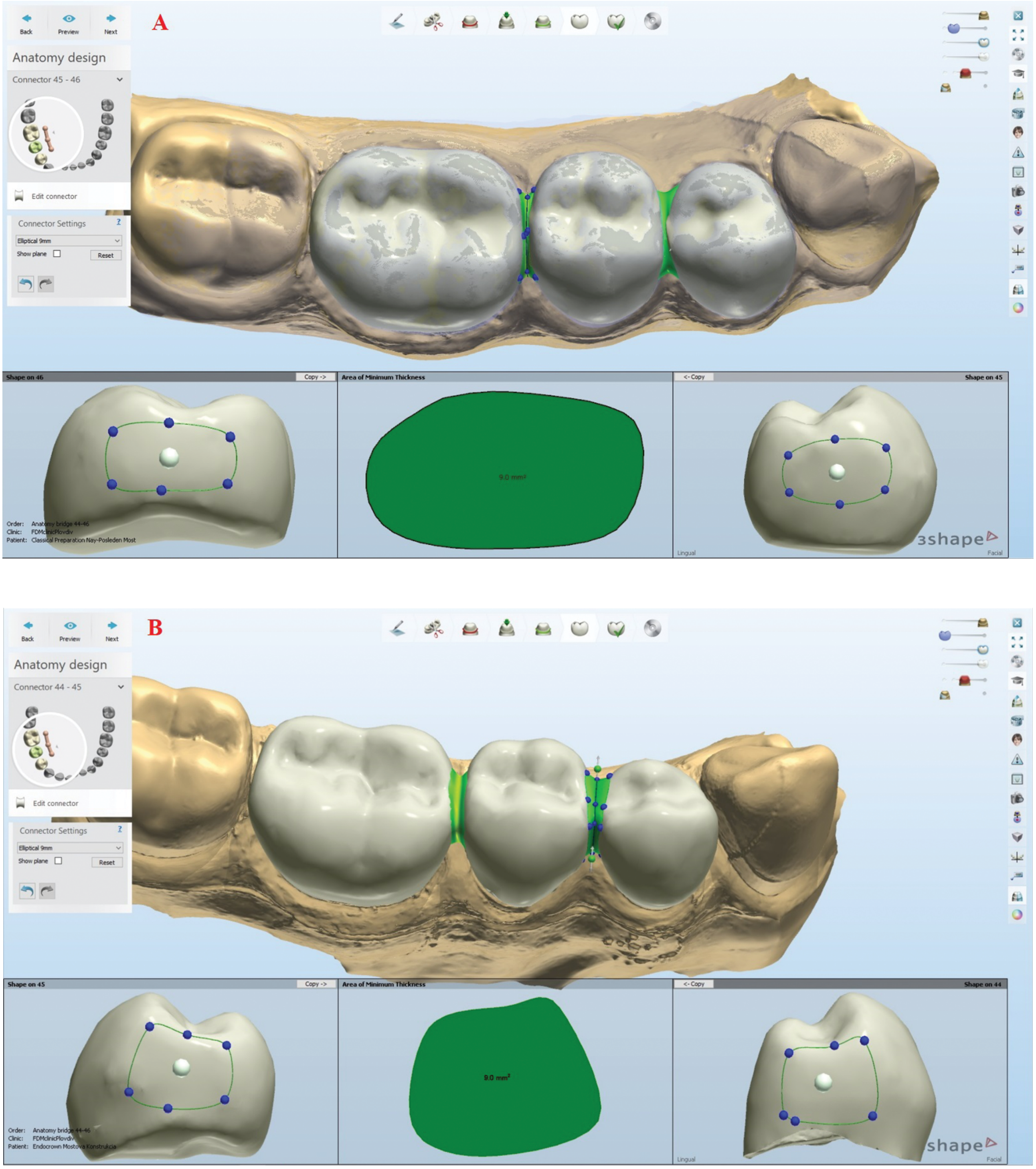

Figure 3. Location and shape of the connector areas: **A**) Distal; **B**) Mesial.

was two-fold. It included a marginal gap test with a dental explorer (Hu-Friedy, Germany). A silicone test with C-silicon impression material (Oranwash VL, Zhermack SpA, Italy) was performed to assess the uniformity of the cement gap between the intaglio surface of the crowns and the abutment teeth.

The assembly of the test specimens – connection between the base and the bridge restoration was made using dual curing resin cement RelyX U200 (3M ESPE, USA). Surfaces in contact with the cement were treated with 70% ethyl alcohol prior to the luting procedure. Additionally, the intaglio surfaces of the crowns were treated with Ivoclean (IvoclarVivadent, Luxemburg). The excess cement was carefully removed. The curing was performed with GC D-light Duo (GC, Europe) for 10 seconds per side.

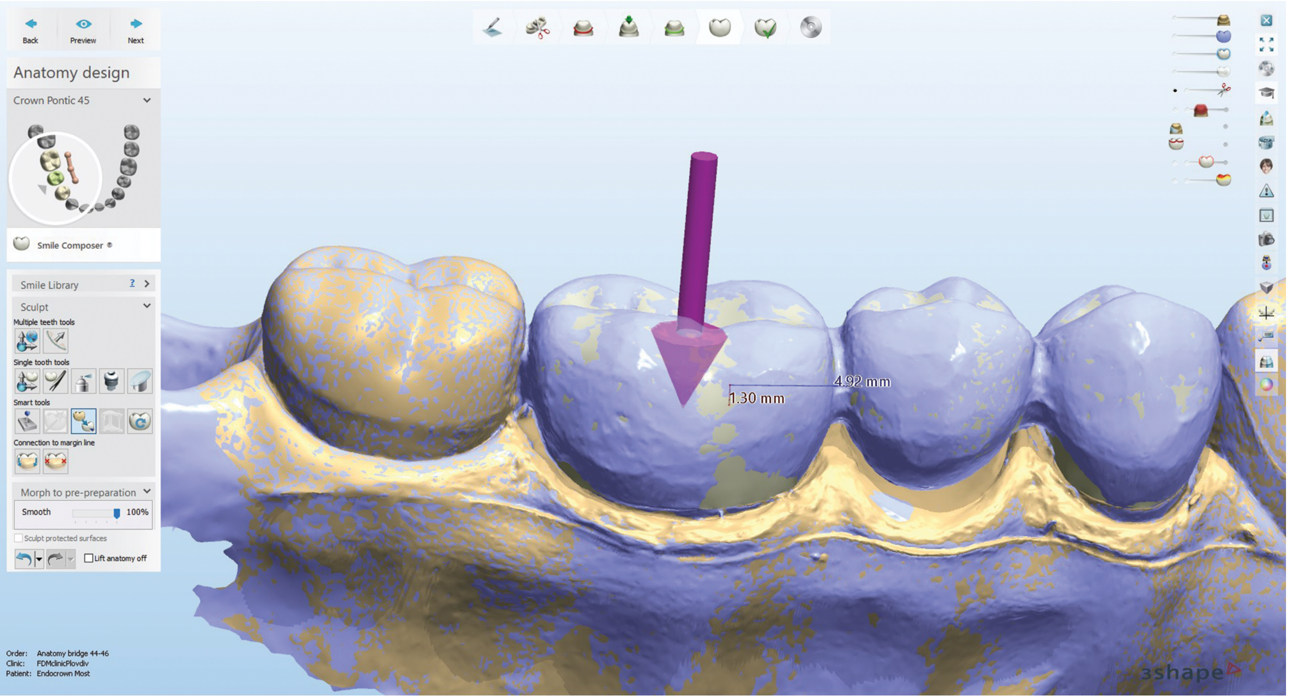

Figure 4. Pre-scan of the finished bridge restoration from the classical preparation group.

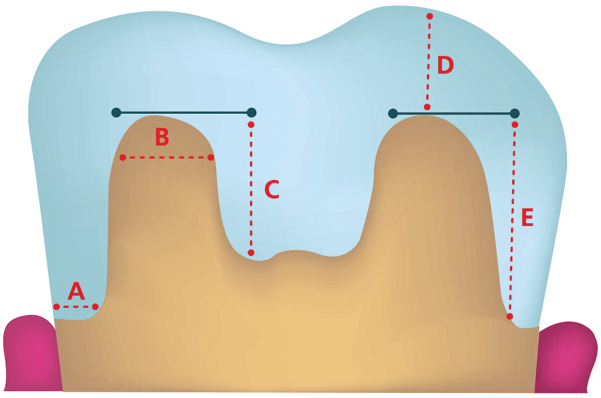

Figure 5. Features of endocrown preparation: A - 0.8 mm, B - ≥1.5 mm, C - ≥2.00 mm, D - ≥1.5 mm, E – ≥3 mm.

Fracture resistance test

The fracture resistance test was performed using a universal testing machine Zwick (Germany) in the Danube Private University, Krems, Austria. The loading element was a sphere with a diameter of 5 mm. The assembled specimens (bridge and base) were fixed on the working plate and the loading element was positioned in contact with the occlusal surface of the pontic until a uniform contact with the 3 cusps was achieved. The machine working protocol was set at 1 N preload with an increase of 5 N per second. The specimen design allowed a load direction parallel to the vertical axis of the teeth (**Fig. 7**).

Figure 6. Test specimen bases and bridge restorations for both groups.

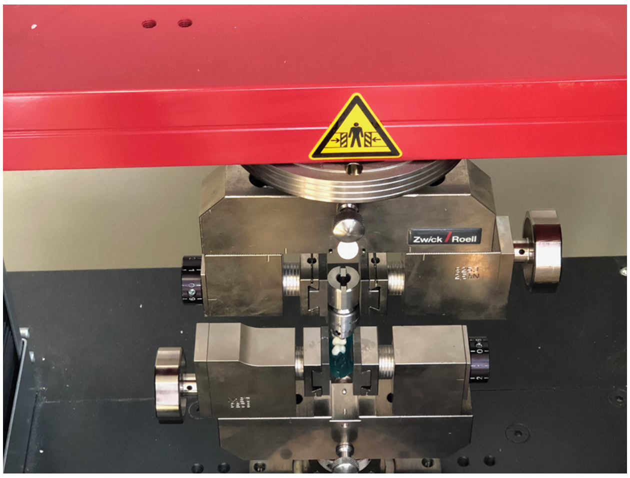

Figure 7. Test setting in the universal testing machine.

Hypothesis and statistical tests

The following working hypotheses were defined:

H0 – There is no difference between the forces required to fracture the FPDs with the two preparation designs of the distal abutment teeth ($\mu2 - \mu1 = 0$) *

Ha – The force needed to fracture bridges with a distal retainer – endocrown is significantly larger or lower than that required for bridges with a distal retainer – full crown ($\mu2 - \mu1>0 \mid \mu2 - \mu1<0$) * μ1 is the arithmetic mean of the force required to fracture bridge restorations with a distal retainer full crown. μ2 is the arithmetic mean of the force required to fracture bridge restorations with a distal retainer endocrown.

Furthermore, an assessment of the use of endocrown as a distal retainer, which will change the distribution of the forces on the bridge restoration, and which may affect the fracture location was performed. We defined two fracture zones – the distal connector and another area of the specimen.

Statistical analysis includes descriptive statistics, *t*-test for quantitative variables and chi-squared test for qualitative variables. R is used for all statistical computations.

RESULTS

The results of the fracture resistance test are presented in **Table 1** and **Fig. 8**. The mean and standard deviation values are 1099.66±386.98 N for all tested metal-free restorations. The mean ± SD values were 954.9±381.54 N and 1254.3±358.37 N for the C-group and E-group, respectively. The *t*-test revealed no statistically significant difference in the maximum force required to fracture the test specimens, depending on the preparation design of the distal abutment tooth [t=1.8088(17.39), *p*-value=0.087; *p*>0.05].

The second investigated variable was the place of fracture. Nineteen of the FPDs fractured in the distal connector zone and one in the mesial connector area **(Fig. 9)**. The results, analyzed with the chi-squared test, were statistically significant [$\chi^2(1)=28.9$, $p<0.001$].

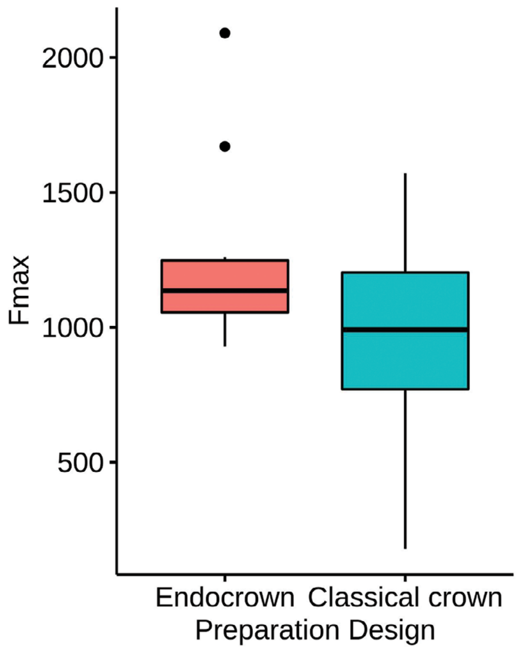

Figure 8. Differences in failure modes between endocrown and full-coverage crown preparation designs.

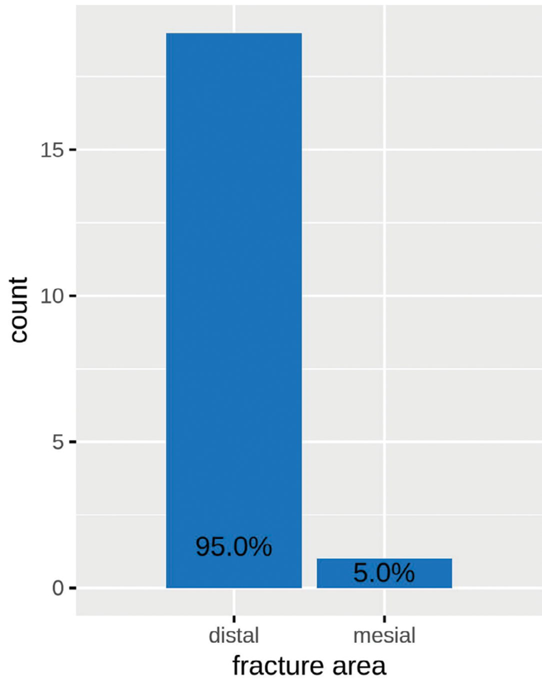

Figure 9. Incidence of fracture at the distal and mesial connector.

DISCUSSION

This *in-vitro* study aimed to assess the effect of different preparation design of the distal abutment tooth in a three unit monolithic ZrO_2 FPDs on their fracture resistance. The results from the conducted experiments support the null

Table 1. Results from the fracture resistance test

Group	N	%	Mean ± SD (in Newtons)	t (df)	*p*
Endocrown	10	50	1254.3±358.37	1.808 (17.93)	0.09
Classical preparation	10	50	954.9±381.54		
Total	20	100	1099.66±386.98	-	-

hypothesis – there is no statistically significant difference between the forces needed to fracture the test specimens.

The obtained nominal values for fracture resistance are in accordance with other reported findings in the literature.[21-23] Some authors describe higher fracture loads ranging from 1607.27 to 3499.9 N for full-contour zirconium dioxide ceramics restorations. However, the design of the studies – single crowns and loading elements with different shape and cross-section, rather than the ones in the present study, might be attributable to the different results.[24,25] Another possible reason is the specific design and the materials used for the FPDs and base fabrication. In the present study, an attempt was made to simulate the intraoral conditions as close as possible, hence the test-bodies were full-contour bridges, and the base was made of resin material with properties that simulate the micro-movements of teeth under loading conditions. Although the test specimens were digitally fabricated and their design essentially copy-pasted, except the intaglio surface of the distal crowns, an imprecise fit between the FPD and the base might influence the fracture resistance results.[26] A limitation of this study is the evaluation of the fit – marginal and overall, that was assessed only trough clinical means – dental explorer and a silicone test.

The design of the gingival embrasure plays an important role in the fracture resistance of FPDs.[14] In the present study, the chosen radius of the notch in both connectors was kept at 0.5 mm in order to minimize the stress concentration in that area. The 3-unit FPDs were manufactured from high-translucent monolithic ZrO_2 ceramics, which is known to have lower strength compared to its opaque counterparts.[27]

The fracture mode of the test specimens in this study was evaluated through progressive loading (5 N/second) with a preload of 1 N. The maximum load required for fracturing the test specimens in this study is more than 1000 N. This is several times greater than the naturally occurring forces during mastication even in patients with parafunctions (bruxism, clenching) and can rarely be achieved in traumatic conditions.[28] The endocrown preparation design showed a higher mean score in comparison with the classical preparation **(Table 1)**. However, results did not show a significant difference, hence it can be assumed that both designs will perform equally well in clinical conditions. A limitation of the obtained results is the lack of mechanical and thermal artificial ageing, which might substantially alter the nominal recorded values, as described previously.[29,30] Considering the aforementioned, the reported information should be translated to clinical conditions with care.

Several studies have investigated the influence of preparation design on the distribution of stress and the fracture resistance. The endocrown shows promising results in simulation studies – FEM, laboratory tests and clinical trials.[6,31] However, all studies concern single crowns, which leaves out the possible use of such preparation design and type of construction as retainers in fixed partial restorations. Our results suggest that endocrown design of the distal retainer can successfully be used in short span bridge restorations in the posterior area of the dentition.

The area of fracture was grouped into two categories – 'distal' and 'mesial' connectors since all specimens fractured in these zones. The distribution of fractures was similar to other reported findings.[7,13] The authors noted that horizontal elliptical shape was more prone to fracture as opposed to the vertical one. A comparison between the C- and E-groups could not be performed for this variable in the current study due to the low number of fractures occurrences for the mesial area.

CONCLUSIONS

Within the limitations of this study, we can conclude that both tested preparation designs show similar results regarding the load required to fracture the test specimens. Furthermore, it is confirmed that the distal connector is the weakest area of an all-ceramic 3-unit FPD in the posterior area.

Acknowledgements

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Стойкость к излому 3-звенных частичных несъёмных протезов из монолитной керамики ZrO_2 с различными конструкциями препарирования дистального абатмента – исследование *in-vitro*

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Резюме

Введение: Жевательное давление увеличивается в дистальных отделах зубных рядов. Это следует учитывать при восстановлении пациентов с частичной адентией безметалловым несъёмным частичным протезом (НЧП). Можно использовать альтернативные конструкции препарирования абатмента, чтобы увеличить объём материалов в наиболее подверженной переломам «зоне соединителя» НЧП. Увеличенный размер соединения может положительно повлиять на механическую прочность конструкции, тем самым повысив её работоспособность и живучесть.

Цель: Целью настоящего исследования было изучение влияния двух вариантов препарирования дистального абатмента на сопротивление разрушению трёхзвенных монолитных НЧП из ZrO_2.

Материалы и методы: Для этого исследования были использованы 3D-печатные копии сегмента нижней челюсти с частичной адентией и ZrO_2, отфрезерованные по полному контуру, трёхзвенные НЧП. Две экспериментальные группы (n=10) были определены на основе конструкции препарирования дистального опорного зуба – классическое препарирование плеча глубиной 0.8 мм и препарирование эндокоронки с ретенционной полостью 2 мм. Сборка мостовидного сегмента с копией нижнечелюстного сегмента была выполнена с помощью relyXU200 (3M ESPE, США), полимеризована в течение 10 секунд с каждой стороны с помощью D-light Duo (GC, Европа). После цементирования образцы подвергались нагружению на универсальной испытательной машине Zwick (Zwick-Roell Group, Германия). Статистический анализ был выполнен с использованием R и включает описательную статистику, t-критерий для количественных и критерий хи-квадрат для качественных переменных.

Результаты: Результаты не показали различий между двумя исследованными группами по максимальному усилию, необходимому для разрушения испытуемых образцов [t=-1.8088 (17.39), p-значение=0.087; P>0.05]. 95% линий переломов располагались в дистальном соединителе.

Заключение: С учётом ограничений данного исследования можно сделать вывод, что обе испытанные конструкции препарирования показывают схожие результаты с точки зрения нагрузки, необходимой для разрушения испытуемых образцов. Кроме того, подтверждено, что дистальный коннектор является самым слабым местом цельнокерамической 3-звенной НЧП в задней области.

Ключевые слова

3-звенный мостовидный протез, дистальный коннектор, стойкость к излому, керамика из диоксида циркония, эндокоронка