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Fracture resistance of CAD-CAM all-ceramic surveyed crowns with different occlusal rest seat designs

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PURPOSE. To investigate the fracture resistance of monolithic CAD-CAM all-ceramic surveyed crowns with two different occlusal rest seat designs. **MATERIALS AND METHODS.** Two maxillary first premolar were prepared for all-ceramic surveyed crowns with wide (2/3rd of buccolingual width of an unprepared tooth) or narrow (1/3rd of buccolingual width of an unprepared tooth) disto-occlusal rest seat (ORS) designs. Eighty monolithic CAD-CAM all-ceramic surveyed crowns were prepared and divided into 4 groups - Group CR, Composite resin material as a control; Group LDS, Lithium disilicate based material; Group ZIPS, zirconia-material (IPS ZirCAD); and Group ZLHT, zirconia- material (CeramillZolidht+). Crowns were cemented on an epoxy resin die with adhesive resin cement. The fracture resistance of crowns was tested with the universal machine. Univariate regression analysis was used. **RESULTS.** The mean ± standard deviation of maximum failure force values varied from 3476.10 ± 285.97 N for the narrow ORS subgroup of group ZIPS to 687.89 ± 167.63 N for the wide ORS subgroup of group CR. The mean ± standard deviation of maximum force was 1075 ± 77.0 N for group CR, 1309.3 ± 283.9 N for group LDS, 3476.1 ± 285.97 N for group ZIPS, and 2666.7 ± 228.21 N for group ZLHT, with narrow occlusal rest seat design. The results of the intergroup comparison showed significant differences in fracture strength with various material groups and occlusal rest seat designs (*P*<.001). **CONCLUSION.** The zirconia-based all-ceramic surveyed crowns fractured at more than double the load of Lithium disilicate based crowns. The crowns with narrow base occlusal rest seat design had statistically significantly higher fracture resistance than surveyed crowns with wide occlusal rest seat design. The use of narrow occlusal rest seat design in CAD-CAM all ceramic surveyed crowns provides higher fracture resistance, and therefore narrow occlusal rest design can be used for providing esthetics with high strength. [J Adv Prosthodont 2021;13:36-45]

KEYWORDS
CAD-CAM; Digital dentistry; Prosthodontics; Removable prosthodontics

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INTRODUCTION

With the accessibility of computer-aided design/computer-aided manufacturing (CAD/CAM) systems and the advent of higher-strength all-ceramic materials, the trend to replace metal-ceramic crowns with highly esthetic all-ceramic materials is increasing. Metal-ceramic crowns are currently the most commonly used crowns for fixed prostheses,[1] but when demand of esthetics is high, all-ceramic crowns are preferred as they are visually appealing and biocompatible.[1-4] Although the previously used all-ceramic materials had a limitation of low fracture resistance but newer materials are more promising in this aspect. Fixed restorations prepared from the zirconia-based ceramics have been reported as alternatives to metal-ceramic surveyed crowns for RPDs.[5-7] All ceramic materials are inert, resistant to corrosion, and have reduced electrical conductivity and temperature. Thus, the application of all-ceramic crowns has become popular because of easy fabrication, superior esthetics, and biocompatibility.[7]

In recent years, all-ceramic crowns with superior toughness and strength have been produced to achieve the normal functions of the teeth. Regardless of their success, a few all-ceramic crown restorations fail after years of function.[5,7] As stated in a clinical report by Sattar *et al*., the major reason for the failure of the ceramics is fracture.[8] Since the reported longevity of all-ceramic restorations is 97.3% in 5 years, 93.5% in ten years, and 78.5% in 20 years, its drawn-out progress remains the main issue for prosthodontists.[6]

Zirconia and lithium disilicate based materials are comparatively newly introduced materials for fixed prosthesis. These are used as a core material for individual crowns, a conventional fixed dental prosthesis (FDPs), and resin-bonded bridges; it proves to be a suitable option in higher stress situations.[4] These materials have good fracture resistance that withstands occlusal forces (150 - 665 N);[9] the fracture strengths of CAD/CAM zirconia machined restorations are more than 1000 N.[10,11]

A fixed restoration on a tooth that acts as an abutment for a removable partial denture (RPD) is regarded as one of the most complex restorative procedures in Prosthodontics.[9] The single crown in RPD abutments are used to support clasp assembly and had been described as surveyed crowns.[6] The all-ceramic crowns can be produced by either heat-pressing the ceramics material or fabricating with CAD/CAM from a block of machinable ceramic. Production of a porcelain fused to metal restoration fabrication is complex and lengthy, because repeated surveying in the laboratory is necessary to design and produce an accurate outline in the final restoration.[8] On the other hand, CAD/CAM system makes a surveyed crown as it scans and duplicates the anticipated contour or shape of waxing or cast restoration in a simple way.[10,12]

An all-ceramic zirconia based fixed prosthesis has been recommended as a reliable and effective alternative to conventional metal-ceramic crowns or FDP's.[10] Properly designed restorations with the adequate distribution of loads of RPD's on an abutment tooth could increase the durability of both the RPD and other oral structures.[13,14]

The occlusal rest seat for an RPD gives longitudinal support and permits occlusal loads to be transferred along the long axis of the abutment tooth. Moreover, the correct shape of the occlusal rest seat and abutment tooth permits suitable occlusal load transfer, stability, and retention. Occlusal rest seats have shown to be strong when made on enamel, amalgam, or composite resin.[9]

The characteristics of all-ceramic crowns, particularly its brittleness, and the shape for the occlusal rest seat should be suitable, sufficiently thick, and adequately firm. In evaluating the fracture strength of monolithic crowns, the bulk of the restoration material is tested.[15] Lan *et al*.[16] stated that a diameter of 0.7 mm of a nonanatomic core was enough for withstanding cyclic fatigue forces at an axial and 10° angled force of a zirconia crown. Sun *et al*.[17] reported the fracture strength of various diameters of blocked zirconia crowns in the anatomic form of mandibular molars where the antagonistic load focused on the center of a tooth, inside the crown. The fracture resistance values were 1814.6 ± 68.21 N for the 0.8 mm diameter and 4109.93 ± 610.18 N for the 1.5 mm diameter of zirconia restorations.[17]

In the present study, occlusal rest preparations that were assessed had different buccolingual widths. The recommended guidelines of occlusal rest seat design

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in buccolingual width should be 1/3 to 2/3 the buccolingual width of the tooth or 1/2 the distance between the cusp tips.[18-20] When considering the recommendations that the occlusal rest seat design should be 2.0-mm broad, the adequate width ranged from 1.53 mm to 4.0 mm.[21]

To our best knowledge, studies on the fracture strength of CAD-CAM all-ceramic crowns with relation to the various preparations of the occlusal rest seats are missing. The objective of the current *in vitro* study was to compare fracture resistance of monolithic CAD-CAM all-ceramic surveyed crowns with two different occlusal rest seat designs in the abutments of RPD. The null hypothesis was that no variations would exist in the fracture strength of CAD-CAM ceramic crowns for RPD abutments with different occlusal rest seat designs (wide and narrow base occlusal rest seat).

MATERIALS AND METHODS

The present study was conducted in King Khalid University, Abha, KSA, in the Department of Prosthodontics, College of Dentistry, and was approved by the institute's ethics committee (SRC/ETH/2018-19/136). To standardize the study protocol, a synchronized flowchart was prepared for the fabrication of samples (Fig. 1). Two extracted well-formed intact human maxillary first premolars (#14) were selected from the institute's extracted teeth bank, disinfected, and stored in 0.1% thymol solution. Later, both the teeth were mounted in clear acrylic resin (Orthodontic Resin, Dentsply Sirona, Mount Waverley, Australia), keeping the junction between cementum and enamel at 2 mm above the acrylic resin base. Following this, these teeth were prepared for the all-ceramic surveyed crown with a disto-occlusal rest seat (ORS). 1.0 mm reduction was

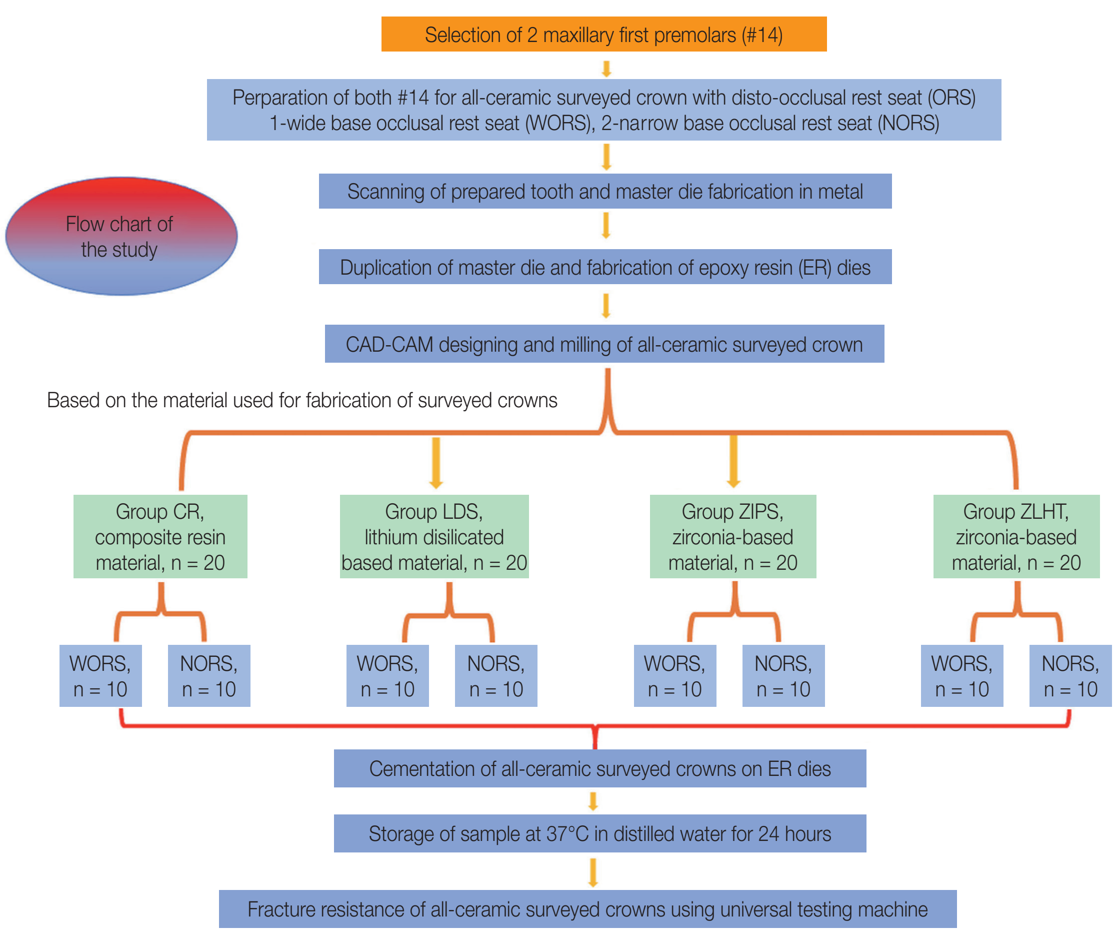

Fig. 1. Flow chart of study.

done in the facial and axial side, 2.0-mm reduction on occlusal surface, and rounded shoulder finish line with 1-mm width was made circumferentially with 10 degrees of taper. 0.85 mm average thickness was kept at the center of the floor of the rest seat in each tooth. Based on ORS width, one tooth was designated with a wide base occlusal rest seat and the other with a narrow base occlusal rest seat. In the wide base occlusal rest seat, the width of ORS was 2/3rd of the buccolingual width of unprepared premolar, while in narrow base occlusal rest seat, the width was 1/3rd of the buccolingual width of an unprepared premolar.

Subsequently, the scanning of prepared teeth was done with a desktop scanner (Ceramill Map 400, Amann Girrbach, Vorarlberg, Austria) and the data was saved as a standard tessellation language (STL) file format. These STL files were later transferred to a 3D printer (Form 2 3D printer Formlabs Inc., Somerville, MA, USA), and printed in castable resins (Formlabs Dental SG Resin, Somerville, MA, USA) with a diameter of 0.05 mm for each layer and maximum laser speed was 5,000 mm/s. Using these printed models, master models were made in metal [cobalt-chromium (Wirobond C, BEGO GmbH, Bremen, Germany)] after casting. The master metal dies prepared were duplicated in epoxy resin dies. A total of 80 dies were prepared.

Next, the STL files of prepared teeth were transferred to CAD software (Cerec InLab 4.2, Dentsply Sirona, Mount Waverley, Australia) for the designing of full coverage surveyed crowns with pre-decided ORS design. Two virtual crowns having 0.5 mm of cementation space and different widths of ORS were designed. The final crown production was done using a milling machine with 5-axes (Ceramill Motion 2, Amann Girrbach, Vorarlberg, Austria) with a bur diameter of 1 mm and 3 mm following the manufacturer's recommendation.

Four groups were made based on the tooth-colored materials used for the fabrication of surveyed crowns: Group CR, Composite resin material (MZ100 Blocks, 3M ESPE, St. Paul, MN, USA) used as a control (Rest seats are considered to be stable when prepared from restorative materials such as composite resin[7]) (n = 20); Group LDS, lithium disilicate based material (IPS e.max CAD Planmill MT A1 C14, IvoclarVivadent AG, Amherst, NY, USA) (n = 20); Group ZIPS, zirconia-material (IPS e.maxZirCAD LT, IvoclarVivadent AG, Amherst, NY, USA) (n = 20); and Group ZLHT, zirconia-material (Ceramill Zolid ht+ High Translucent Zirconia, Amann Girrbach, Vorarlberg, Austria) (n = 20) as shown in (Table 1).

Crowns of the individual groups were further segregated into 2 subgroups with two different shapes of occlusal rest seat design: wide base occlusal rest seat (WORS) subgroup (n = 10), and narrow base occlusal rest seat (NORS) subgroup (n = 10). After milling, the crowns were finally sintered, polished and glazed following the manufacturer's instructions for each material. Representative crown samples of both ORS designs are shown in (Fig. 2). For the groups ZLHT and ZIPS, the tissue surfaces of the samples were air-abraded with 50-μm aluminium oxide at 0.2 MPa for 10 seconds followed by conditioning with a universal adhesive agent (Scotchbond Universal Adhesive, 3M ESPE, St. Paul, MN, USA) for 20 seconds. The

Table 1. Groups and material used for fabrication of all-ceramic surveyed crowns

Group	Materials	Composition	Manufacturer	Occlusal rest seat design
CR	MZ100 Blocks Shade A	Composite resin	3M ESPE, St. Paul, MN, USA	wide base narrow base
LDS	IPS e.max CAD Planmill MT A1 C14	Lithium disilicate	IvoclarVivadent AG, Amherst, NY, USA	wide base narrow base
ZIPS	IPS e.maxZirCAD LT	Zirconia	IvoclarVivadent AG, Amherst, NY, USA	wide base narrow base
ZLHT	Ceramill Zolid ht High Translucent	Zirconia	Amann Girrbach, Vorarlberg, Austria	wide base narrow base

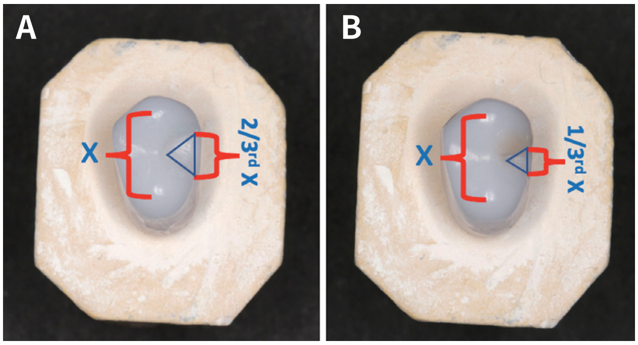

Fig. 2. Representative images of all ceramic surveyed crowns with 2 occlusal rest seat designs. (A) wide occlusal rest seat-WORS; (B) narrow occlusal rest seat- NORS.

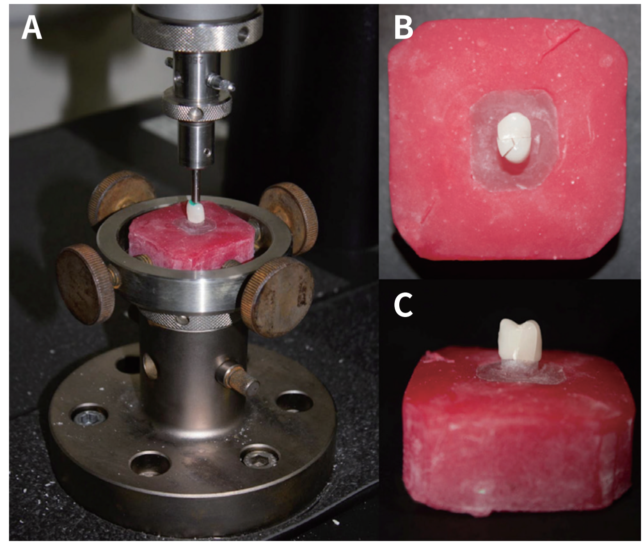

Fig. 3. (A) Specimen in position for compression test in universal testing machine, (B) fractured crown - occlusal view, (C) fractured crown-axial view.

epoxy resin dies were applied with the same adhesive agent for 20 seconds and dried with air for 5 seconds. The cementation of crowns was done by dual-polymerizing adhesive resin cement (RelyX Ultimate Adhesive Resin Cement, 3M ESPE, St. Paul, MN, USA). 70% ethyl alcohol was used to clean the crowns of group CR on the intaglio surface and then the crowns were conditioned and cemented similar to zirconia groups. For standardization, the same operator performed all bonding procedures.

For LDS group crowns, 5% hydrofluoric acid for 20 seconds was used, and then the crowns were cleaned and immersed in distilled water and subsequently cleaned in an ultrasonic bath for 5 minutes following the manufacturer's recommendations. The internal surface of the crowns was then applied with Monobond Plus (IvoclarVivadent AG, Amherst, NY, USA) for 60 seconds. A bonding agent (Adhese, IvoclarVivadent AG, Amherst, NY, USA) was applied for 20 seconds and then dried with air, and then the crowns were cemented with resin cement (VLEsthetic DC, IvoclarVivadent AG, Amherst, NY, USA).

All crown samples were kept in distilled water at 37°C for 24 hours before testing. The testing of the samples was done in a universal testing machine (Model 5855, Intron Corp.). To prevent the slipping of the rod and to avoid concentrations of forces at irregularities on the occlusal surface, part of the rubber dam was positioned between the surface crown and the rod of the Instron machine. A static compressive axial load was applied in the center of each crown in such a way that force was exerted on the triangular ridges of both buccal and palatal cusps, at a crosshead speed of 1 mm/min through a 3.5 mm diameter of rod head. The compressive force (in N) at fracture was noted for every sample as failure load (Fig. 3). The data obtained were assessed using descriptive statistics and making comparisons among the various groups (Mean & SD).

Univariate regression analysis was used to find effects of material & occlusion rest seat design. 95% confidence limits were applied to see the significantly higher or lower values of fracture strength for various materials & ORS designs. The *P*-value was taken significant when less than 0.05 ($P < .05$) and a confidence interval of 95% was taken.

RESULTS

The mean ± standard deviation of maximum failure force values varied from 3476.10 ± 285.97 N for the narrow ORS subgroup of group ZIPS to 687.89 ± 167.63 N for the wide ORS subgroup of group CR. Both zirconia-based groups ZIPS and ZLHT crown fracture strengths were statistically significantly greater than IPS e.max CAD and LDS crown fracture strengths ($P < .05$) (Table 2). All checked material groups showed statistically significantly higher maximum failure

Table 2. Intergroup comparison of fracture strength for various material groups and occlusal rest seat design

Material group		Mean	SD
CR	N-ORS	1075.07	77.60
	W-ORS	687.89	167.63
	CR Total	881.48	235.82
LDS	N-ORS	1309.30	239.60
	W-ORS	937.83	108.18
	LDS Total	1123.56	262.78
ZIPS	N-ORS	3476.10	285.97
	W-ORS	2968.92	319.71
	ZIPS Total	3222.51	393.51
ZLHT	N-ORS	2666.70	228.21
	W-ORS	2083.82	400.88
	ZLHT Total	2375.26	436.11
Total	N-ORS	2131.79	1020.81
	W-ORS	1669.61	964.96
	Total	1900.70	1014.00

force for the narrow ORS design when compared with the wide ORS design ($P < .05$).

All the ZIPS and ZLHT crown fracture strengths with N-ORS showed significantly higher strengths, lying above the 95% upper confidence limit, while all the

Table 3. Intergroup comparison of fracture strength for various material groups and occlusal rest seat design

Source	F	*P*-value	Effect size
Intercept	4624.15	< .001	0.985
Material Group	385.61	< .001	0.941
ORS design	68.35	< .001	0.487
Material + Design	0.81	.491	0.033

CR & LDS crown fracture strengths showed significantly lower strengths, lying below the 95% lower confidence limit which (Fig. 4).

The results of the intergroup comparison (univariate regression analysis) showed significant differences in fracture strength in various material groups ($P < .001$) and occlusal rest seat designs ($P < .001$). However, no significant interaction effect of material & design was present in fracture strength (F = 0.81, $P = .491$). Further, the effect of the material was more significant than the occlusal design based on effect size estimation (0.941) (Table 3).

DISCUSSION

The mastication forces in humans have been noted to be nearly 40 N, while the mean maximum posterior teeth masticatory forces range from 200 to 540 N.[22] The average fracture forces for composite materi-

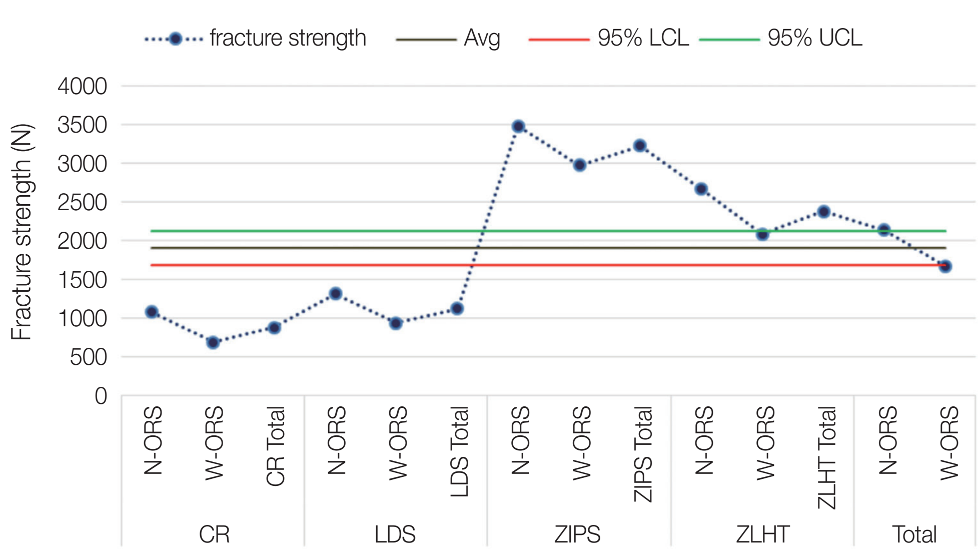

Fig. 4. Results of fracture strength for various material groups and occlusal rest seat design.

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al and all-ceramic crowns were reported higher than the common masticatory loads. Körber *et al*. reported in their study that single crowns should have more than 450 N fracture strength and bridges should have more than 500 N fracture strength in the mouth.[23] According to the findings of the current study, it was observed that the minimum fracture resistance value was 687.89 N, which was in accordance with the study of Körber *et al*., in which they reported that the fracture strength value for a single crown should be higher than 450 N.[23]

The findings of the current study showed that different CAD-CAM all-ceramic zirconia-based surveyed crowns with two occlusal rest seat preparations would have a range of fracture resistance for RPD abutments which was greater than the recorded occlusal loads. In the present study, CAD-CAM zirconia crowns had adequate strength to resist the highest occlusal loads calculated in young dentate persons; on the other hand, the composite resin and the lithium disilicate may not have enough strength compared to zirconia-based crowns.[14,17]

Regarding the fracture resistance testing, the present study showed that there was a considerable statistically significant difference between mean fracture resistance values of zirconia and lithium disilicate in both the narrow and wide occlusal rest seat designs; hence the null hypothesis formulated was rejected. In the current study, the zirconia crowns fracture resistance values were also accordant with the findings of Sun *et al*.[17] The surveyed crowns with narrower base occlusal rest seat preparation had approximately 20% more fracture strength than the surveyed crowns with wide occlusal rest seat design.

The designs of all the surveyed crowns were identical and duplicable because the crowns were made with a CAD-CAM machine utilizing an STL file record for all the crowns. The current study inspected the influence of two different occlusal rest seat preparations made of CAD-CAM system on fracture strength of tooth-colored surveyed crowns. Testing conditions and model materials were selected cautiously to reproduce clinical condition as faithfully as possible. Design of teeth and dimensions of the occlusal rest seats were carried out according to the standard protocol. All crowns were fabricated by a single technician of the dental laboratory following a similar protocol using the zirconia, lithium disilicate, and composite materials. The epoxy resin was used for die fabrication as its elastic modulus is the same as that of human dentin.[5] The resistance analysis procedure is frequently used to assess the mechanical characteristics of the loaded samples directing to controlled failure at the point of stress concentration under controlled laboratory conditions.[15,24]

Contradicting to the findings of the present study, Martinez-Rus *et al*.[25] reported higher fracture strength of titanium abutments restored with lithium disilicate crowns than zirconia abutments. They reasoned that because of the low load-bearing capacity of glass-ceramics in comparison to titanium, lithium disilicate crowns were demarcated as the weakest components in abutment-crown assemblies, so implant abutment made of titanium didn't fracture. Titanium abutment-manually veneered zirconia crown combinations presented no crown fracture but only implant neck distortion.

The mean fracture strength of the zirconia crowns in the present study was more than 2000 N in all groups, which is more than the normal mastication load of 300 N to 600 N.[5] The fracture strength experienced in the current study could be compared well to the previous *in vitro* studies.[7,12,16,17] As in a zirconia crown, less deformation is produced because of its increased elastic modulus; as a result, less stress is provoked in the zirconia crowns, but overloaded zirconia inevitably results in fracture of the crowns.[26]

The result showed that the width of the rest seat greatly affected the strength of the surveyed crown. NORS design was superior to the WORS in terms of fracture strength. Combining the results from NORS and WORS, narrow was considered to be better as it would result in more thickness of ceramic material around the cuspal area resulting in higher strength and also offers the merits of less abutment preparation than the wide rest.[27] Moreover, the narrower rest designs were mechanically stronger in zirconia crown than the lithium disilicate, thus withstanding the heavy loads. The ideal outlines of rest seats had not been scientifically determined until now. In current study, 1/3 and 2/3 B-L widths of the rest seats on the occlusal surface were proposed for all-ceramic surveyed crowns on premolars and NORS proved better as it would provide bulk to the crown material. On the other hand, the abutment may get greater stress in the tooth with narrower than wide occlusal rest seat preparations. Sato *et al*. noted that the strength (the structural resistance of the occlusal rest seat) decreases with width.[28] However, two-third occlusal rests are ideal, as reported by most authors.[28,29]

In accordance with the current study, Sagsoz[12] reported that the fracture resistance of lithium disilicate crowns (787.99 N) was lower than the fracture strength of zirconia crowns (843.18 N). With the findings of the study, it was apparent that the fracture resistance of zirconia crowns with NORS proved superior to the lithium disilicate. The significant difference was associated with the special properties of the zirconia that made them remarkable for application as surveyed restorations. Additional investigations of zirconia carried out in permanent crown restorations by Nakamura *et al*.,[29] Kim *et al*.,[30] Vagkopoulou *et al*.,[31] and Denry and Kelly[32] also determined that zirconia crowns were of superior quality in comparison to the crowns fabricated from other all-ceramic materials.

Zirconia has altered the traditional management ideas of surveyed crowns and RPDs. The superior esthetics provided by the zirconia crown compared to metal or metal-ceramic crown enhanced the acceptance by the patient even though the RPD framework is of metal.[6,31-33] The findings of the present study proved that the zirconia crowns were capable to withstand the maximum load until fracture in comparison to the lithium disilicate crowns.[34,35] Single zirconia crowns with NORS are appropriate for clinical application in abutment teeth in cast RPDs. Fracture in the veneering porcelain stays a concern even with veneered zirconia, while the zirconia surface in occlusal rest seats for RPDs proved no wear. Ohlmann *et al*. stated that the fracture resistance of zirconia with NORS is more than the lithium disilicate and composite resin crowns depend notably on the occlusal diameter of the crowns and the type of cement used.[36]

The limitations of the study included static loading and the direction of load perpendicular to the occlusal surface. Temperature and the oral environment effects were also not regarded. The standardization of the milling machine was not assessed; the number of axes and cuts possessed by the milling machine and frequency of bur used might have affected the precision of prepared crowns.[37] Also, the final crown dimensions used in this trial were also cautiously adapted using non-shrinkable epoxy resin index taken after tooth preparation to simulate posterior teeth. Future studies are recommended to overcome the above limitation points with an *in vivo* assessment of the same.

CONCLUSION

Within the limitations of this *in vitro* study, it can be concluded that the CAD-CAM zirconia-based surveyed crowns had higher fracture resistance than lithium disilicate based surveyed crowns. The shape of the occlusal rest seat design effected fracture strength of all-ceramic surveyed crowns. Designing rest seats with less B-L (narrow base occlusal rest seat design) width statistically increases fracture resistance, independent of the material used thus can be used for providing esthetics with high strength.

REFERENCES

1. Freire Y, Gonzalo E, Lopez-Suarez C, Suarez MJ. The marginal fit of CAD/CAM monolithic ceramic and metal-ceramic crowns. J Prosthodont 2019;28:299-304.
2. Rodríguez V, Castillo-Oyagüe R, López-Suárez C, Gonzalo E, Peláez J, Suárez-García MJ. Fracture load before and after veneering zirconia posterior fixed dental prostheses. J Prosthodont 2016;25:550-6.
3. Pelaez J, Cogolludo PG, Serrano B, Serrano JF, Suarez MJ. A four-year prospective clinical evaluation of zirconia and metal-ceramic posterior fixed dental prostheses. Int J Prosthodont 2012;25:451-8.
4. Martínez-Rus F, Suárez MJ, Rivera B, Pradíes G. Evaluation of the absolute marginal discrepancy of zirconia-based ceramic copings. J Prosthet Dent 2011;105:108-14.
5. Elshiyab SH, Nawafleh N, Öchsner A, George R. Fracture resistance of implant- supported monolithic crowns cemented to zirconia hybrid-abutments: zirconia-based crowns vs. lithium disilicate crowns. J Adv Prosthodont 2018;10:65-72.
6. Carracho JF, Razzoog ME. Removable partial den-

ture abutments restored with all-ceramic surveyed crowns. Quintessence Int 2006;37:283-8.
7. Manchester JA, Chung KH, Brudvik JS, Ramos V Jr, Chen YW. F racture resistance of cingulum rest seats in CAD-CAM tooth-colored crowns for removable partial enture abutments. J Prosthet Dent 2019;121:828-35.
8. Sattar J, Al Hmedat A, Jaber ZA. A comparison of fracture strength among different brands of translucent zirconia crown restorations. J Bio Agriculture Healthc 2016;6:111-9.
9. Gouveia DNM, Razzoog ME, Alfaro MF. A fully digital approach to fabricating a CAD-CAM ceramic crown to fit an existing removable partial denture. J Prosthet Dent 2019;121:571-5.
10. Bethke A, Pieralli S, Kohal RJ, Burkhardt F, von Stein-Lausnitz M, Vach K, Spies BC. Fracture resistance of zirconia oral implants in vitro: a systematic review and meta-analysis. Materials (Basel) 2020;13:562.
11. Shahrbaf S, van Noort R, Mirzakouchaki B, Ghassemieh E, Martin N. Fracture strength of machined ceramic crowns as a function of tooth preparation design and the elastic modulus of the cement. Dent Mater 2014;30:234-41.
12. Sagsoz NP, Yanıkoglu N. Evaluation of the fracture resistance of computer-aided design/computer-aided manufacturing monolithic crowns prepared in different cement thicknesses. Niger J Clin Pract 2018;21:417-22.
13. Pihlaja J, Näpänkangas R, Kuoppala R, Raustia A. Veneered zirconia crowns as abutment teeth for partial removable dental prostheses: a clinical 4-year retrospective study. J Prosthet Dent 2015;114:633-6.
14. Yoon TH, Chang WG. The fabrication of a CAD/CAM ceramic crown to fit an existing partial removable dental prosthesis: a clinical report. J Prosthet Dent 2012;108:143-6.
15. Miura S, Kasahara S, Yamauchi S, Katsuda Y, Harada A, Aida J, Egusa H. A possible risk of CAD/CAM-produced composite resin premolar crowns on a removable partial denture abutment tooth: a 3-year retrospective cohort study. J Prosthodont Res 2019;63:78-84.
16. Lan TH, Pan CY, Liu PH, Chou MMC. Fracture resistance of monolithic zirconia crowns in implant prostheses in patients with bruxism. Materials (Basel) 2019;12:1623.
17. Sun T, Zhou S, Lai R, Liu R, Ma S, Zhou Z, Longquan S. Load-bearing capacity and the recommended thickness of dental monolithic zirconia single crowns. J Mech Behav Biomed Mater 2014;35:93-101.
18. Glann G, Appleby R. Mouth preparation for removable partial dentures. J Prosthet Dent 1960;10:698-706.
19. Perry C. A philosophy of partial denture design. J Prosthet Dent 1956;6:775-84.
20. Miller E, Grasso J. Removable partial prosthodontics. 2. ed. Baltimore: Williams and Wilkins; 1981.
21. Culwick PF, Howell PG, Faigenblum MJ. The size of occlusal rest seats prepared for removable partial dentures. Br Dent J 2000;189:318-22.
22. Attia A, Abdelaziz KM, Freitag S, Kern M. Fracture load of composite resin and feldspathic all-ceramic CAD/CAM crowns. J Prosthet Dent 2006;95:117-23.
23. Sampaio-Fernandes MA, Sampaio-Fernandes MM, Fonseca PA, Almeida PR, Reis-Campos JC, Figueiral MH. Evaluation of occlusal rest seats with 3D technology in dental education. J Dent Educ 2015;79:166-76.
24. Chung SM, Yap AU, Tsai KT, Yap FL. Elastic modulus of resin-based dental restorative materials: a microindentation approach. J Biomed Mater Res B Appl Biomater 2005;72:246-53.
25. Martínez-Rus F, Ferreiroa A, Özcan M, Bartolomé JF, Pradíes G. Fracture resistance of crowns cemented on titanium and zirconia implant abutments: a comparison of monolithic versus manually veneered all-ceramic systems. Int J Oral Maxillofac Implants 2012;27:1448-55.
26. Brijawi A, Samran A, Samran A, Alqerban A, Murad M. Effect of different core design made of computer-aided design/computer-aided manufacturing system and veneering technique on the fracture resistance of zirconia crowns: a laboratory study. J Conserv Dent 2019;22:59-63.
27. Rice JA, Lynch CD, McAndrew R, Milward PJ. Tooth preparation for rest seats for cobalt-chromium removable partial dentures completed by general dental practitioners. J Oral Rehabil 2011;38:72-8.
28. Sato Y, Shindoi N, Koretake K, Hosokawa R. The effect of occlusal rest size and shape on yield strength. J Prosthet Dent 2003;89:503-7.
29. Nakamura K, Harada A, Inagaki R, Kanno T, Niwano Y, Milleding P, Örtengren U. Fracture resistance of monolithic zirconia molar crowns with reduced thickness.

Acta Odontol Scand 2015;73:602-8.
30. Kim JH, Park JH, Park YB, Moon HS. Fracture load of zirconia crowns according to the thickness and marginal design of coping. J Prosthet Dent 2012;108:96-101.
31. Vagkopoulou T, Koutayas SO, Koidis P, Strub JR. Zirconia in dentistry: part 1. discovering the nature of an upcoming bioceramic. Eur J Esthet Dent 2009;4:130-51.
32. Denry I, Kelly JR. State of the art of zirconia for dental applications. Dent Mater 2008;24:299-307.
33. Anupama PD, Parakh MK, Krishna PD. Methods to enhance esthetics in removable prosthesis - a narrative review. Int J Clin Dent 2020;13:317-28.
34. Kashkari A, Yilmaz B, Brantley WA, Schricker SR, Johnston WM. Fracture analysis of monolithic CAD-CAM crowns. J Esthet Restor Dent 2019;31:346-52.
35. Okada R, Asakura M, Ando A, Kumano H, Ban S, Kawai T, Takebe J. Fracture strength testing of crowns made of CAD/CAM composite resins. J Prosthodont Res 2018;62:287-92.
36. Ohlmann B, Gruber R, Eickemeyer G, Rammelsberg P. Optimizing preparation design for metal-free composite resin crowns. J Prosthet Dent 2008;100:211-9.
37. Kirsch C, Ender A, Attin T, Mehl A. Trueness of four different milling procedures used in dental CAD/CAM systems. Clin Oral Investig 2017;21:551-8.