Comparison of Retention and Fracture Load of Endocrowns Made from Zirconia and Zirconium Lithium Silicate After Aging: An in-Vitro Study

Majid Sahebi

Tehran University of Medical Sciences

Safoura Ghodsi

Tehran University of Medical Sciences

Parsia Berahman

Tehran University of Medical Sciences

Amirhesam Amini

Tehran University of Medical Sciences

Somayeh Zeighami (✉ somayeh.zeighami@gmail.com)

Tehran University of Medical Sciences

Research Article

Keywords: CAD-CAM, Compressive Strength, Dental Prosthesis Retention, Endocrown, Zirconia

Posted Date: November 15th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-1071606/v1>

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Version of Record: A version of this preprint was published at BMC Oral Health on February 16th, 2022.

See the published version at <https://doi.org/10.1186/s12903-022-02072-x>.

Abstract

Background: This study aimed to compare retention and fracture load in endocrowns made from zirconium lithium silicate and translucent zirconia.

Methods: Fifty-six intact human maxillary molars after being mounted in acrylic resin, were scanned to acquire biogeneric copies. Specimens underwent standard endodontic treatment and were prepared for endocrown up to 2 mm above the cemento-enamel junction. The specimens were randomly divided into two groups of 28 and endocrowns were designed using biogeneric copies and milled from high-translucent zirconia disks (Zr) and zirconium lithium silicate blocks (ZLS). After cementation with dual cure resin cement, all the specimens underwent thermomechanical aging and pull-out retention test and compressive test were conducted (14 specimens were used for each test in each group, $n=14$) and failure modes in both tests were evaluated.

Results: Independent samples t-test showed significant difference between the retention of Zr ($271.5 \text{ N} \pm 114.31$) and ZLS ($654.67 \text{ N} \pm 223.17$) groups (p value = 0.012). Compressive test results were also significantly different between Zr ($7395.07 \text{ N} \pm 1947.42$) and ZLS ($1618.3 \text{ N} \pm 585$) ($p = 0.002$). Failure mode of retention test was primarily adhesive failure at the cement-restoration interface in Zr group and cement-tooth interface in ZLS group. Failure modes of fracture test for Zr group were 7 non-restorable fractures and one restorable fracture while 6 specimens resisted compressive loads up to 8500 N without fracture. ZLS group showed 7 restorable and 7 non-restorable failures.

Conclusions: Zr endocrowns showed significantly lower retention and higher fracture strength. Both materials seem to be suitable for fabrication of endocrown in clinical setup.

Background

There has always been the challenge of pointing out the best technique for restoring endodontically treated teeth [1]. The functional requirements and the extent of coronal tissue destruction are two most important determinants in selecting the most efficient way of restoring devitalized teeth; Therefore, a single treatment plan cannot be applied to all the cases [2]. Endodontically treated teeth are prone to biomechanical failures [3]. The primary reason can be attributed to the reduction in stiffness and fracture resistance as the consequences of loss of integrity (caries, trauma, and access cavity preparation) [4]. Using intracanal posts might seem essential due to extensive loss of coronal tissue and lack of sufficient retention [5]. Although clinical success of post, core and crown has been ascertained in the literature, this method is not free of shortcomings [3, 6].

The complications of routine procedures have led to the introduction of novel methods and restorations including endocrown, which was innovated in 1995 by Pissis [7]. These adhesive monoblock full ceramic restorations play the role of post, core and crown at the same time [5]. This category of restorations is mainly, but not exclusively, used in the molar region and benefits from both macro- and micro-retention [8–10]. As micro-retention plays the fundamental role in retention of an endocrown restoration, it seems

essential to use a material that can be etched and adhesively bonded; for example, glass containing ceramics like zirconium lithium silicate [8–11]. This newly introduced glass ceramic, besides from outstanding aesthetics, has mechanical properties similar and even higher than lithium disilicate [11]. On the other hand, zirconia, a polycrystalline ceramic with no amorphous glassy phase, has drawn lots of attention to its superb mechanical characteristics [12–14], especially as a material to be used in high stress conditions [15, 16]. Zirconia cannot be etched by routine methods and its retention in a partial coverage restoration like endocrown is not as reliable as other ceramics. It is noteworthy to mention that debonding is the most common cause of failure in endocrown restorations [17, 18]. However, a combination of mechanical and chemical treatment has proved to be beneficial in increasing the bond strength of zirconia with tooth. For example, sandblasting with silica-coated particles (that allows the association of silane primers) and traditional alumina sandblasting (combined with the use of chemical promoters like 10-MDP-based products) [19].

Few studies have assessed the mechanical behavior and clinical performance of zirconia endocrowns and have mostly focused on the fracture strength [20–23], while the most challenging factor in zirconia application in endocrowns seems to be its retention which is not addressed in previous studies. Competency of zirconia as a material in crown fabrication has been verified in the literature [24, 25]. Considering differences between crown and endocrown regarding preparation design, area covered by the restoration, finish line width, and shape of the restoration, this study aimed to assess and compare the retention and fracture load of CAD-CAM fabricated endocrowns made of zirconium lithium silicate (ZLS) (as one of the prevalent materials in fabricating endocrown) and translucent zirconia (Zr) after thermomechanical aging and to evaluate failure modes after retention and fracture tests. The null hypotheses were that there are no significant differences in retention and fracture load between Zr and ZLS.

Methods

Fifty-six intact human maxillary molars, extracted for orthodontic or periodontic reasons, were collected for this study as specimens. None of the specimens were extracted more than 2 months prior to the study. The specimens were stored in Hank's balanced saline solution at room temperature, and the storage medium was replaced every two weeks [26]. All of the specimens were measured by a vernier caliper (INSIZE, Suzhou, China); the teeth had to be 11 ± 1 mm in buccolingual, 10 ± 1 mm in mesiodistal, and 7.5 ± 1 in occlusogingival dimensions to enter the study.

Upper and lower casts with perfect occlusion were made by pouring the impressions of a typodont by type 4 dental stone (Asia chemi teb pharmaceutical Co, Tehran, Iran). A trapezoidal space was prepared on each side of the upper cast in the first molar area to be used as a mold for mounting the specimens. The teeth were mounted vertically in self-cure acrylic resin by a surveyor in occlusion with the opposing tooth.

Before any intervention, the specimens were scanned by a laboratory scanner (inEos X5; Dentsply Sirona, York, PA) to acquire biogeneric copies to replicate tooth's preoperative anatomy. The teeth underwent standard root canal therapy and were prepared with 90° butt margin and 12° wall divergence using a handpiece mounted on a surveyor. Specimens were reduced occlusally up to 2 mm above the cementoenamel junction. The teeth were inspected with a periodontal probe to have 4 mm pulp chamber depth otherwise, they were replaced. The pulpal floor of the teeth with pulp chamber depths higher than 4 mm were lined with restorative glass ionomer (GC Fuji II; GC, Tokyo, Japan). The butt margin was polished and the pulp chamber was cleaned with 95% ethanol.

The specimens were randomly (stratified random allocation) divided into two groups of 28 and the prepared teeth were scanned again. Endocrowns were designed using biogeneric copies (inLAB CAD SW; Dentsply Sirona, York, PA). Cement space was set on zero for the margins and 50 µm for other areas [27]. The restorations were milled (inLab MC X5; Dentsply Sirona, York, PA) from Celtra Duo (Dentsply Sirona, York, PA) in ZLS group and DD Bio ZX² (Dental Direkt, Spenge, Germany) in Zr group. Details of the two ceramics used in this study are summarized in Table 1 [28, 29]. The ZLS restorations were recrystallized (at 820° C) then glazed to reach the maximum mechanical properties and the Zr restorations got fully sintered (at 1450° C) then glazed according to the manufacturer's instructions.

Table 1
Ceramic materials used in the study

Group	Ceramic type	Composition	Flexural strength
ZLS* (Celtra Duo)	Zirconium lithium silicate ceramic	SiO ₂ (58%), P ₂ O ₅ (5%), Al ₂ O ₃ (1.9%), Li ₂ O (18.5%), ZrO ₂ (10.1%), Tb ₄ O ₇ (1%), and CeO ₂ (2%)	Mill and polish: 210 MPa
			Mill and fire: 370 MPa
Zr[†] (DD BIO ZX ²)	High-translucent zirconium oxide ceramic	ZrO ₂ + HfO ₂ + Y ₂ O ₃ (>99%), Y ₂ O ₃ (<6%), Al ₂ O ₃ (≤0.15%), and other oxides	1250 MPa
* Zr: zirconia; † ZLS: zirconium lithium silicate			

The seat of restorations was assessed using Fit checker (GC, Tokyo, Japan) and the passive fit of restorations was confirmed by two impartial observers. Restorations in ZLS group were prepared using 9% hydrofluoric acid (Cera-Etch; Morvabon, Tehran, Iran) and silane (Master-Dent Porcelain Primer; Dentonics, Charlotte, NC) while Zr restorations were sandblasted with 50 µm alumina particles and cleaned using ultrasonic device [30]. The specimens were cemented by Panavia F2.0 (Kuraray, Tokyo, Japan) dual cure resin cement, which contains 10-MDP, according to the manufacturer's instructions. To standardize the cementation process, all the specimens were placed under 5 kg weight for 5 minutes. Cemented specimens were kept in an incubator at 37° for 24 hours.

Specimens underwent thermomechanical aging including 5000 thermal cycles (C-300; Vafaei industrial factory, Qom, Iran) in 5 °C and 55 °C distilled water with 25 seconds dwell time to simulate 6 months of clinical service [31, 32], and 500,000 loading cycles with 50 N force and 1.64 Hz frequency via a round metal cone (4 mm diameter) in 100% humidity environment (Chewing Simulator CS-4; SD Mechatronik, Feldkirchen-Westerham, Germany) to simulate 2 years of clinical service [32, 33].

14 Zr and 14 ZLS specimens were randomly selected for retention test. Each specimen was mounted individually in the lower compartment of universal testing machine (UTM) (ProLine; ZwickRoell, Ulm, Germany) while the endocrown part was held and fixed between two layers of leather and the upper compartment clips (Fig. 1a). The leather layers were used to reduce the possibility of endocrown fracture during tightening the upper compartment clips and increasing the friction between the two surfaces. UTM was set on pull-out mode with the speed of 5 mm/min and the pull-out force was applied until complete separation of the restoration and the tooth.

Samples were assessed to evaluate the failure mode after retention test (Fig. 2). The failure modes were classified as type 1 for cohesive failure of cement layer, type 2 for adhesive failure at the cement-tooth interface, type 3 for adhesive failure at the cement-restoration interface, and type 4 for mixed failures [34].

Compressive test was applied on the other 28 samples (14 Zr and 14 ZLS) with UTM and a 4 mm diameter metal cylinder with crosshead speed of 0.5 mm/min on the central fossa of the restorations until fracture or sudden fall in the load graph (Fig. 1b). All the specimens were evaluated for failure mode (Fig. 3). The failure modes of compressive test were classified as type 1 for cohesive failure in endocrown (Restorable), type 2 for adhesive failure or fracture with displacement (Restorable), type 3 for cohesive failure in enamel/dentine (Non-restorable), and type 4 for cohesive failure in both tooth and ceramic structure (Non-restorable) [35].

The data were analyzed using SPSS 22.0 (IBM, Armonk, NY). The normality of data in each group was evaluated using one-sample Kolmogorov-Smirnov test. The effect of material (ZLS vs. Zr) on retention and fracture load of endocrowns was assessed by Independent Samples t-test ($\alpha = 0.05$).

Results

Independent Samples t-test showed that retention force was significantly higher in ZLS group (Table 2).

Table 2
Mean, standard deviation, minimum, and maximum of retention test results in Zr and ZLS groups

Retention (N) (n=14)					
Group	Mean	Standard deviation	Minimum	Maximum	P value
Zr	271.50	114.31	104.71	490.22	0.012
ZLS	654.67	223.17	222.74	1006.25	
Zr: zirconia; ZLS: zirconium lithium silicate					

All zirconia endocrowns were intact after retention test and the retention failure mode was of Type 3. Four of ZLS specimens fractured during the pull-out test; one endocrown was still bonded to the tooth while the tooth suffered root fracture, and the other 3 samples fractured from pulp chamber part of the endocrown. The other 10 samples in ZLS group suffered Type 2 failures.

Results of compressive test showed significantly higher fracture load in Zr group (Table 3).

Table 3
Mean, standard deviation, minimum, and maximum of fracture test results in Zr and ZLS groups

Fracture load (N) (n=14)					
Group	Mean	Standard deviation	Minimum	Maximum	P value
Zr	7395.07	1947.42	4689.00	11141.00	0.002
ZLS	1618.3	585.00	854.00	2752.00	
Zr: zirconia; ZLS: zirconium lithium silicate					

Failure type and restorability of the specimens after fracture test are summarized in Table 4.

Table 4
Failure mode of fracture test in the two study groups.

Failure mode of fracture test			
Both endocrown and tooth were intact (until 8500 N)		Restorable fracture	Non-restorable fracture
Zr	6	Type 1 (n=1)	Type 4 (n=7)
ZLS	-	Type 1 (n=7)	Type 4 (n=7)
Zr: zirconia; ZLS: zirconium lithium silicate			

Discussion

Fracture resistance along with esthetics and marginal adaptation are three of most important factors that determine success of a restoration [16], and since debonding is the primary reason in failure of endocrown restorations [17, 18], this study was designed to assess the competency of translucent zirconia as a new material in fabricating endocrown restorations by comparing the fracture resistance and retention of these restorations with the ones made of ZLS, which is a routine material in endocrown fabrication. To simulate the oral environment as much as possible, in addition to using human extracted teeth, the specimens underwent thermomechanical aging.

The null hypotheses of this study were completely rejected since both fracture load and retention of endocrowns showed significant differences between Zr and ZLS groups.

Pull-out retention force in ZLS group was significantly higher than Zr group. Higher retention in ZLS endocrowns was expected as the glassy phase in ZLS structure allows the restorations in this group to be etched and adhesively bonded to the tooth structure [11]. On the other hand, restorations in Zr group did not benefit from the adhesive bond of resin cement as much as restorations in ZLS group did. Sadighpour et al showed 279.19 N $\pm$ 50.14 retention force in zirconia crowns sandblasted with aluminum oxide particles and cemented with Panavia F2.0 dual cure resin cement which is approximately similar to the retention force in Zr group in the present study (271.50 N $\pm$ 114.31) [34].

There is limited information on required retention force in molar restorations. Brunton et al indicated that mean maximum opening force was 79 N in males with the maximum recorded opening force of 166.61 N [36]. The pull-out force which occurs in molar region while chewing sticky food has been recorded about 150 N [37]. Therefore, it can be concluded both zirconia and ZLS endocrowns have sufficient retention for restoring endodontically treated molars in clinical setup. Zou et al assessed clinical performance of zirconia endocrowns and found no failures including debonding of restoration after 3 years [20], which seems to be an indication of sufficient retention at least in short term follow-ups.

Zirconia does not have the ability of being etched by routine methods [13, 14]. Sandblasting with alumina particles, tribochemical conditioning, and use of other chemical and physical techniques have been proposed to improve the bond strength of zirconia to the tooth structure [13, 14]. The present study used sandblasting technique along with cementation with a resin cement which contained 10-MDP; However, this technique could not provide bond strength comparable to glass ceramic (ZLS) for Zr since the failure mode after retention test indicated that the majority of cement remained on restorations in ZLS group while in Zr group, cement was mostly remained on the tooth structure.

Zr showed fracture load significantly higher than ZLS group. This result was consistent with the results presented by other studies that showed Zr has higher fracture resistance compared to glass ceramics and even metal ceramic restorations [11, 23]. The mean maximum bite force in posterior region was recorded to be 738 N [38]. Both groups in the present study showed sufficient fracture resistances to be used in endocrown restorations in clinical cases. However, maximum voluntary bite forces up to 1642.8 N was recorded in Jansen van Vuuren et al study which is higher than mean fracture load of ZLS group, but lower than Zr group [15]; therefore, it seems in high stress cases like bruxism, zirconia is a more reliable option to be used in endocrown fabrication.

Failure mode after fracture in ZLS group was divided into two groups of restorable and non-restorable with almost equal proportions while in Zr group, even though the number of non-restorable cases were more than restorable cases, the fracture occurred in much greater forces than maximum bite force even in bruxer patients and 6 specimens remained completely intact until compressive load of 8500 N.

The present study was limited to one surface treatment technique in zirconia endocrowns and use of one type of resin cement. Also, more thermomechanical aging cycles could have resulted in different outcomes, especially in zirconia, as it is prone to low temperature degradation. Moreover, only vertical compressive forces were applied on the specimens, which is not according to the dynamic conditions in oral environment. Designing studies, considering the mentioned limitations, could provide more reliable results.

Conclusions

Within the limitations of the present study, following conclusions were obtained:

1. Zirconia endocrowns had fracture loads higher than endocrowns made of zirconium lithium silicate, while zirconium lithium silicate endocrowns showed superior retention.
2. Both zirconia and zirconium lithium silicate seem to be suitable materials for fabrication of endocrown in restoring endodontically treated molars with regard to fracture resistance and retention.
3. Due to high fracture load, use of zirconia in patients with bruxism might be a good suggestion.

Abbreviations

UTM: universal testing machine, 10-MDP: 10-Methacryloyloxydecyl dihydrogen phosphate.

Declarations

Ethics approval and consent to participate

The study protocol was registered and approved in the Institutional Research Ethics Committee at School of Dentistry-Tehran University of Medical Sciences (IR.TUMS.DENTISTRY.REC.1399.054).

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analyzed during the study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

Funding

This study was supported by Tehran University of Medical Sciences and Health Services, Tehran, Iran, grant #98-02-69-42555.

Authors' contributions

MS, SG, and SZ were involved in study design, interpretation of data, and editing the draft manuscript. PB and AA were involved in data acquisition, analysis and preparing the manuscript. All authors read and approved the final manuscript.

Acknowledgements

Not applicable

References

1. Robbins JW. Restoration of the endodontically treated tooth. Dent Clin North Am. 2002;46:2.
2. Faria AC, Rodrigues RC, de Almeida Antunes RP, de Mattos Mda G, Ribeiro RF. Endodontically treated teeth: characteristics and considerations to restore them. J Prosthodont Res. 2011;55:2.
3. Zarone F, Sorrentino R, Apicella D, Valentino B, Ferrari M, Aversa R, et al. Evaluation of the biomechanical behavior of maxillary central incisors restored by means of endocrowns compared to

- a natural tooth: a 3D static linear finite elements analysis. *Dent Mater.* 2006,22:11.
4. Chang C-y, Kuo J, Lin Y-S, Chang Y-H. Fracture resistance and failure modes of CEREC endo-crowns and conventional post and core-supported CEREC crowns. *J Dent Sci.* 2009,4:3.
 5. Sevimli G, Cengiz S, Oruc MS. Endocrowns: review. *J Istanbul Univ Fac Dent.* 2015,49:2.
 6. Dietschi D, Duc O, Krejci I, Sadan A. Biomechanical considerations for the restoration of endodontically treated teeth: a systematic review of the literature, Part II (Evaluation of fatigue behavior, interfaces, and in vivo studies). *Quintessence Int.* 2008,39:2.
 7. Pissis P. Fabrication of a metal-free ceramic restoration utilizing the monobloc technique. *Pract Periodontics Aesthet Dent.* 1995,7:5.
 8. Lander E, Dietschi D. Endocrowns: a clinical report. *Quintessence Int.* 2008,39:2.
 9. Biacchi G, Basting R. Comparison of Fracture Strength of Endocrowns and Glass Fiber Post-Retained Conventional Crowns. *Oper Dent.* 2012,37:2.
 10. Veselinović V, Todorović A, Lisjak D, Lazic V. Restoring endodontically treated teeth with all-ceramic endo-crowns: Case report. *Stom Glas S.* 2008,55-64
 11. Traini T, Sinjari B, Pascetta R, Serafini N, Perfetti G, Trisi P, et al. The zirconia-reinforced lithium silicate ceramic: lights and shadows of a new material. *Dent Mater J.* 2016,35:5.
 12. Zarone F, Sorrentino R, Vaccaro F, Traini T, Russo S, Ferrari M. Acid etching surface treatment of feldspathic, alumina and zirconia ceramics: A micromorphological SEM analysis. *Int Dent South Afr.* 2011,8:3.
 13. Zarone F, Di Mauro MI, Ausiello P, Ruggiero G, Sorrentino R. Current status on lithium disilicate and zirconia: a narrative review. *BMC Oral Health.* 2019,19:1.
 14. Pilo R, Dimitriadi M, Palaghia A, Eliades G. Effect of tribochemical treatments and silane reactivity on resin bonding to zirconia. *Dent Mater.* 2018,34:2.
 15. Jansen van Vuuren L, Broadbent JM, Duncan WJ, Waddell JN. Maximum voluntary bite force, occlusal contact points and associated stresses on posterior teeth. *J R Soc N Z.* 2020,50:1.
 16. Contrepois M, Soenen A, Bartala M, Laviole O. Marginal adaptation of ceramic crowns: a systematic review. *J Prosthet Dent.* 2013,110:6.
 17. Bernhart J, Bräuning A, Altenburger MJ, Wrbas KT. Cerec3D endocrowns—two-year clinical examination of CAD/CAM crowns for restoring endodontically treated molars. *Int J Comput Dent.* 2010,13:2.
 18. Thomas RM, Kelly A, Tagiyeva N, Kanagasingam S. Comparing endocrown restorations on permanent molars and premolars: a systematic review and meta-analysis. *British Dental Journal.* 2020,in press
 19. Scaminaci Russo D, Cinelli F, Sarti C, Giachetti L. Adhesion to Zirconia: A Systematic Review of Current Conditioning Methods and Bonding Materials. *Dent J (Basel).* 2019,7:3.
 20. Zou Y, Bai J, Xiang J. Clinical performance of CAD/CAM-fabricated monolithic zirconia endocrowns on molars with extensive coronal loss of substance. *Int J Comput Dent.* 2018,21:3.

21. Skalskyi V, Makeev V, Stankevych O, Pavlychko R. Features of fracture of prosthetic tooth-endocrown constructions by means of acoustic emission analysis. *Dent Mater.* 2018,34:3.
22. Dartora NR, Maurício Moris IC, Poole SF, Bacchi A, Sousa-Neto MD, Silva-Sousa YT, et al. Mechanical behavior of endocrowns fabricated with different CAD-CAM ceramic systems. *J Prosthet Dent.* 2021,125:1.
23. Kanat Ertürk B, Sarıdag S, KÖSeler E, Yiğit D, Avcu E, Yıldırım Avcu Y. Fracture strengths of endocrown restorations fabricated with different preparation depths and CAD/CAM materials. *Dent Mater J.* 2018,37:2.
24. Mikeli A, Walter MH, Rau SA, Raedel M, Raedel M. Three-year clinical performance of posterior monolithic zirconia single crowns. *The Journal of Prosthetic Dentistry.* 2021,in press
25. Soleimani F, Jalali H, Mostafavi AS, Zeighami S, Memarian M. Retention and Clinical Performance of Zirconia Crowns: A Comprehensive Review. *Int J Dent.* 2020,2020
26. Is Khinda V, Kaur G, S Brar G, Kallar S, Khurana H. Clinical and Practical Implications of Storage Media used for Tooth Avulsion. *Int J Clin Pediatr Dent.* 2017,10:2.
27. Pedrollo Lise D, Van Ende A, De Munck J, Umeda Suzuki TY, Cardoso Vieira LC, Van Meerbeek B. Biomechanical behavior of endodontically treated premolars using different preparation designs and CAD/CAM materials. *J Dent.* 2017,59
28. Al-Zordk W, Saker S. Impact of sintering procedure and clinical adjustment on color stability and translucency of translucent zirconia. *J Prosthet Dent.* 2020,124:6.
29. Attaallah AM, Zayed EM, Dabees SM, Ashour YY, Fahmy AE-E. Comparison between Biaxial Flexural Strength and Microstructure of Polished and Glaze-Fired Specimens of Zirconia Lithium Silicate Glass Ceramic. *Journal of Dental Materials and Techniques.* 2019,8:3.
30. Haralur SB, Alamri AA, Alshehri SA, Alzahrani DS, Alfarsi M. Influence of Occlusal Thickness and Radicular Extension on the Fracture Resistance of Premolar Endocrowns from Different All-Ceramic Materials. *Applied Sciences.* 2020,10:8.
31. Smith ED, Martin FE. Microleakage of glass ionomer/composite resin restorations: a laboratory study. 1. The influence of glass ionomer cement. *Aust Dent J.* 1992,37:1.
32. Gale MS, Darvell BW. Thermal cycling procedures for laboratory testing of dental restorations. *J Dent.* 1999,27:2.
33. Taha D, Spintzyk S, Sabet A, Wahsh M, Salah T. Assessment of marginal adaptation and fracture resistance of endocrown restorations utilizing different machinable blocks subjected to thermomechanical aging. *J Esthet Restor Dent.* 2018,30:4.
34. Sadighpour L, Fazel A, Geramipناه F, Allahdadi M. Effect of Resin Cement Mixing Method on the Retention Strength of a CAD/CAM Zirconia Crowns. *J Indian Prosthodont Soc.* 2014,14:Suppl 1.
35. Ghoul WE, Özcan M, Tribst JPM, Salameh Z. Fracture resistance, failure mode and stress concentration in a modified endocrown design. *Biomaterial investigations in dentistry.* 2020,7:1.

36. Brunton PA, Loch C, Waddell JN, Bodansky HJ, Hall R, Gray A. Estimation of jaw-opening forces in adults. *Orthod Craniofac Res.* 2018;21:1.
37. Kawata T, Yoda N, Kawaguchi T, Kuriyagawa T, Sasaki K. Behaviours of three-dimensional compressive and tensile forces exerted on a tooth during function. *Journal of Oral Rehabilitation.* 2007;34:4.
38. Braun S, Bantleon HP, Hnat WP, Freudenthaler JW, Marcotte MR, Johnson BE. A study of bite force, part 1: Relationship to various physical characteristics. *Angle Orthod.* 1995;65:5.

Figures

Figure 1

Specimen mounted in UTM during pull-out test (a) and compressive test (b)

Figure 2

Specimens after retention test, a: specimen in Zr group with Type 3 failure and remaining cement (arrows) on the tooth structure, B: specimen in ZLS group with Type 2 failure and no remaining cement on the tooth structure, C: specimen in ZLS group with fracture within the tooth (n=1), D: specimen in ZLS group with fracture in the pulp chamber part of restoration (n=3)

Figure 3

Specimen failure mode after compressive test, a: Type 1 failure (ZLS), b: Type 4 failure (Zr).