Khalij-Libya Journal
of Dental and Medical Research
http://journals.khalijedental.com.ly/index.php/ojs/index eISSN:2708-888X

Original article

In Vitro Evaluation of Occlusal Thickness On the Fracture Resistance of CAD-CAM Monolithic Zirconia Molar Crowns

Enas Khamakhim*, **Saleha Al Alwani**

Department of Fixed Prosthodontics, Faculty of Dentistry and Oral Surgery, University of Tripoli, Libya

Corresponding Email. *e.khamakhim@uot.edu.ly*

ABSTRACT

Background and objectives. *Many dental practitioners have always struggled with obtaining aesthetic restorations while preserving the remaining dental structure. The purpose of this study is to investigate the relationship between the occlusal thickness and fracture resistance of CAD/CAM monolithic zirconia restorations to determine the feasibility of reducing the occlusal thickness, particularly in the posterior area, where inter-occlusal space is typically limited and high biting forces are applied.* ***Methods***. *Four experimental groups were created using thirty-two CAD-CAM monolithic zirconia crowns with different occlusal thicknesses: 2.0 mm (group 1), 1.5 mm (group 2), 1.0 mm (group 3), and 0.5 mm (group 4). Self-adhesive resin cement was used to cement the restorations to human molars. Loading the specimens until fracture occurred, and the fracture resistance and mode of failure were recorded. The data were statistically analyzed using a one-way ANOVA followed by Fisher's exact test.* ***Results***. *All specimens' fracture resistance values exceeded the maximum physiological occlusal loads in molar areas, and all of the crowns had consistent microcracks. A complete fracture was only interested in one crown with a thickness of 0.5 mm.* ***Conclusion***. *The occlusal thickness of CAD-CAM monolithic zirconia crowns can be decreased to 0.5 mm while still being strong enough to sustain occlusal loads.*

Keywords: Fracture, Resistance, Monolithic, Zirconia, Crowns, Thickness.

Citation: Khamakhim E, Al Alwani S. In Vitro Evaluation of Occlusal Thickness On the Fracture Resistance of CAD-CAM Monolithic Zirconia Molar Crowns. Khalij-Libya J Dent Med Res. 2023;7(2):63–72. https://doi.org/10.47705/kjdmr.237202

Received: 11/05/23; **accepted**: 03/06/23; **published**: 09/06/23

INTRODUCTION

The name zirconium is derived from the Arabic word Zargon, which means "golden color," which is derived from two Persian words, Zar (gold) and Gon (color) [1, 2]. Dental ceramics have many advantages, including biocompatibility and the ability to simulate the optical properties of natural teeth [3]. Furthermore, the high hardness, chemical inertia, and improved esthetics make zirconia-based ceramics an attractive replacement material for lost dental structures. Adhesion to zirconia, on the other hand, can be difficult, as evidenced by several reports, surface treatments designed to improve zirconia bonding to resin cement, such as particle blasting and the use of 10-MDP-based primers, silanes, and/or resin cement [4].

Because of its mechanical properties and superior esthetic over metal alloys, zirconia has become a popular framework material for all-ceramic restorations [5]. Still, concerns have been raised about zirconia-based prostheses, primarily because of the risk of veneering porcelain chipping [6, 7].

This issue has been solved by newly developed monolithic zirconia restorations that do not require veneering porcelain. Furthermore, using a computer-aided design (CAD) or computer-aided manufacturing (CAM) technique without a veneering process can improve quality with a high degree of homogeneity while potentially lowering costs. Due to the material's high strength, monolithic zirconia crowns have adequate fracture resistance for dental crown restorations. This is due to a property known as stress-induced transformation toughening in yttria-stabilized zirconia [8]. Under stress, a crystalline phase transformation from tetragonal to monoclinic occurs, resulting in a local volume expansion of the crystals. As a result, compressive stress is generated around the crack, preventing further crack propagation. It has been proposed that monolithic zirconia crowns have sufficient fracture resistance to be used in molar regions even if the crown thickness is thinner than conventional all-ceramic crowns. Nakamura et al. [9] demonstrated that monolithic zirconia crowns with a minimum thickness of 0.5 mm had a mean fracture load of over 5000 N, which was significantly higher than monolithic lithium disilicate crowns with a crown thickness of 1.5 mm [10].

Full-contour restorations have great occlusal detail and are in their final shape; high translucency allows the material to blend naturally with neighboring teeth [11]. Zirconia's mechanical behavior can change as new generations emerge. Translucent zirconia today has higher yttria content, a cubic phase, and varying-grain morphology [12].

Previous in vitro research by Sun et al. (2014), Lameira et al. (2015) and Lan et al. (2015) demonstrated that monolithic zirconia SCs had higher fracture loads than layered zirconia restorations. [13, 14, 15]. Thin monolithic zirconia crowns are expected to be a new minimally invasive treatment option. However, several issues must be addressed before thin, monolithic crowns can be widely used.

After aging and mechanical cycling, monolithic crowns proved to be more resistant than bilayered ones [16]. Preparation design and low-temperature degradation have a substantial impact on fracture resistance. [17]. Material and geometrical properties are critical in maximizing the longevity of monolithic zirconia restorations [18].

There have been very few clinical studies on zirconia restorations published to date. Recent clinical studies revealed that CAD-CAM monolithic zirconia crowns had negligible horizontal marginal discrepancies and provided satisfactory clinical results [19]. Furthermore, after 68 months of operation, no mechanical complications (i.e., fracture, cracking, or chipping) were observed [20]. As a result, the goal of this research is to assess the fracture resistance and failure mode of a CAD/CAM molar crown made of a highly translucent zirconia block with varying occlusal thickness, particularly in the posterior oral area, where limited inter-occlusal space is usually available and heavy biting forces are usually applied.

METHODS

Specimen preparation

The study used thirty-two sound-extracted human maxillary third molars. To standardize the size of the selected teeth a digital caliper (S235, Sylvac, Switzerland) was used to measure the bucco-lingual and mesio-distal dimensions of each molar at the cemento-enamel junction. To avoid the formation of microcracks, the selected teeth were cleaned with an ultrasonic scaler at low speed and under copious water coolant to remove dental plaque, calculus, and external debris. Before the study, the teeth were kept hydrated at room temperature in distilled water. Each tooth was placed in an epoxy resin block. For the construction of the epoxy resin block, a plastic cylinder (2 cm in height and 1.5 cm in diameter) was used as a mold. The mold was centralized and fixed to the lower table of a dental surveyor (Ney surveyor, Lukadent Gmbh, Germany) at zero tilt (horizontal position). After that, the tooth was lowered into the cylinder's center to be embedded in the epoxy resin, leaving 1 mm of the root exposed.

Tooth Preparation

Each tooth sample received a standardized full crown preparation using a high-speed handpiece with water coolant. During the tooth preparation technique, the specimen containing the tooth was adjusted and secured to the surveyor's movable table in such a way that the long axis of each clinical crown remained parallel to the stone bur. After that, each tooth sample was prepared for zirconium crown restoration with the following features: 1 mm axial reduction, 0.7 peripheral rounded mini chamfer shoulder placed 0.5 mm above the cemento-enamel junction, 12° of total occlusal convergence; all preparation angles were rounded [21, 22].

Fabrication of Crowns

A three-dimensional digital image for each tooth sample was taken by a Zirconzahn scanner (S600, Italy) (Figure 1). The 3D geometry of each tooth was scanned to fabricate CAD-CAM monolithic crowns. The crown was then designed in the "model" phase, which determined the margin of the preparation that the system automatically detected. The undercut was checked, the path of insertion was determined, and the position of the tooth in the arch was also determined (Figure 2). The data of the crown design were transferred to the Roland milling machine (Roland DWX-50 5-axis, Japan) to mill the block of highly translucent zirconia (Figure 3). The specimens were sintered in a Zirconzahn furnace according to the manufacturer's recommendations.

Sample grouping

The 32 crowns were divided into four groups of eight specimens each (n = 8) with varying occlusal thickness as follows: 2.0 mm (group 1), 1.5 mm (group 2), 1.0 mm (group 3), and 0.5 mm (group 4) (Figure 4).

Figure 1: Zirconzahn scanner

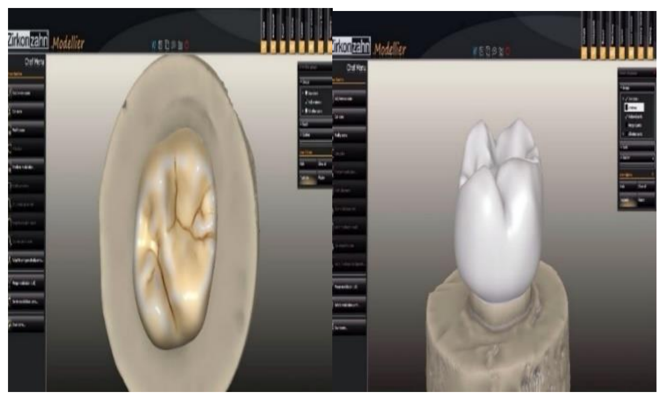

Figure 2: CAD finalization of monolithic zirconia single crown

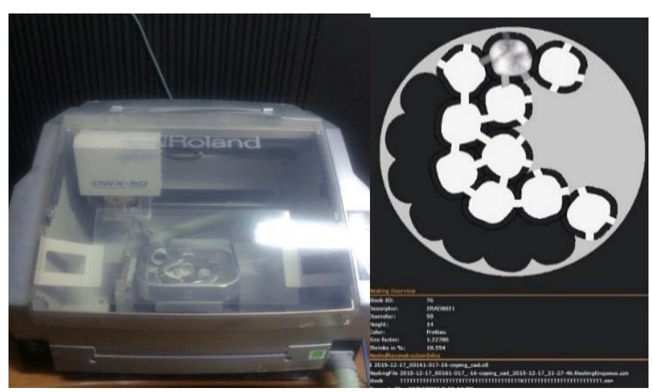

Figure3: CAD process by Roland milling machine

Figure 4: Sample grouping (group1)

Cementation of Crown Restoration

Before the cementation procedure, all groups' teeth were cleaned with alcohol to remove debris. To standardize the amount of luting agent during the cementation procedure, the self-adhesive luting agent was injected inside the inner surface of the crown until it was filled. After seating each crown with finger pressure to fit the tooth, a static load of 5 kg was applied for 6 minutes by a specially developed stainless steel load applicator weighing 2 kg to standardize the load applied on the samples throughout the cementation procedure. Excess material was removed with a fine micro brush before complete polymerization, and each surface was light-cured for 40 s with an LED curing unit (Elipar S10, 3M ESPE, Seefeld, Germany). All specimens were then stored in distilled water at room temperature and tested after one week after cementation [23].

Testing Procedure

A fracture determination test was performed using a universal testing machine (Model LRX-Plus, Lloyd Instruments, Fareham, UK), and the specimen was secure in its position on the machine. A tin foil sheet was put between the loaded applicator and the sample to provide equal stress distribution and reduce the transmission of local force peaks. The loading force was then applied along the long axis of the cemented crowns at the center of the occlusal surface. In (Figure 5), a slowly increasing vertical load (1 mm/min) was applied until a fracture occurred [24].

Fracture mode analysis

Fractured samples were examined to determine the type of fracture mode using a magnification lens (X = 15). (Marx, Japan). The type of failure was assigned according to the Failure Modes Index (according to Burke F.J. 1999) [25].

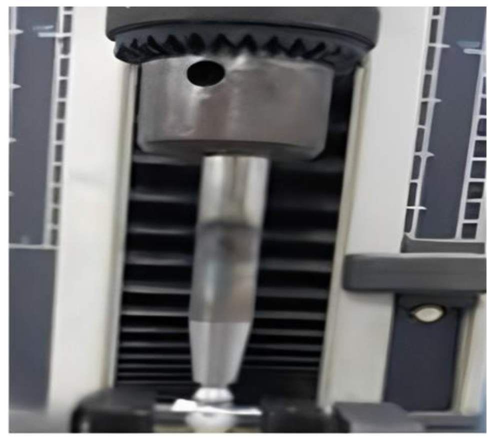

Figure5: Fracture resistance testing

Statistical analysis

The recorded data were statistically analyzed with dedicated software (IBM SPSS version 28). To confirm the normality of the data distribution, the Shapiro-Wilk test was utilized. The differences in fracture resistance among the groups were analyzed using one-way ANOVA; Fisher's exact test was used to determine whether statistically significant differences were detected among the experimental groups. The significance level was set at 0.05.

RESULTS

The Shapiro-Wilk test did not show evidence of non-normality; W (32) = 0.97, p-value =0.776. The data is normally distributed (Figure 6). The results revealed that there were no statistically significant differences between groups for fracture strength ($p > 0.05$). It can be seen that group 1 showed the highest fracture

Khalij-Libya Journal
of Dental and Medical Research
http://journals.khalijedental.com.ly/index.php/ojs/index eISSN:2708-888X

resistance, while the lowest was noticed in group 4 (Table 1). The survival rate of molar CAD-CAM monolithic zirconia SCs in the current study was 100% in groups 1, 2, and 3, and 90% in group 4.
The means and standard deviations were used to summarize the variables of the fracture load values of the four experimental groups, as shown in (Table 2) (figure 7).
All the crowns showed cohesive microcracks of the zirconia in the occlusal region, **(**Mode 1) according to the failure modes index (Table 3), particularly at the level of the load application area, and a complete fracture was only of interest to one crown in Group 4.

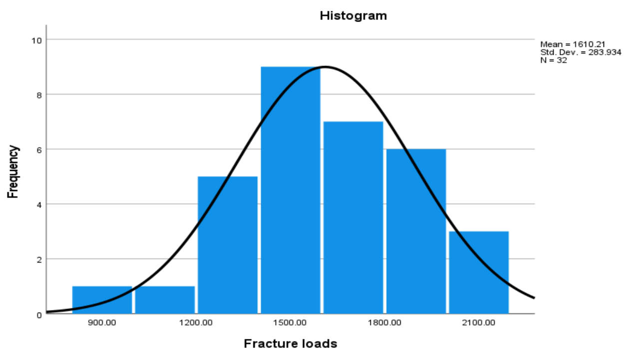

Figure 6: Normal distribution curve

Table 1: Fracture Load Value

Samples	Group 1	Group 2	Group 3	Group 4
	2mm occlusal thickness	1.5mm occlusal thickness	1mm occlusal thickness	0.5mm occlusal thickness
	Fracture load(N)	Fracture load(N)	Fracture load(N)	Fracture load(N)
1	1703.35	1719.88	1780.71	1255.11
2	1820.31	1558.66	1280.42	1220.41
3	1731.08	1381.43	1431.68	889.96
4	1820.50	1538.74	2012.13	1558.83
5	1745.13	1412.82	1172.07	2044.07
6	1871.51	1307.11	1453.33	1456.88
7	1832.56	1971.44	1703.88	1589.76
8	1849.43	1768.48	2120,45	1524.57

Table2: The means and standard deviations of the fracture load values of each group

Fracture load (N)	*Group one 2mm*	*Group two 1.5mm*	*Group three 1.0mm*	*Group four 0.5mm*
Mean	1796.73	1582.32	1619.33	1442.44
Standard Deviation	61.48	224.33	341.48	336.74

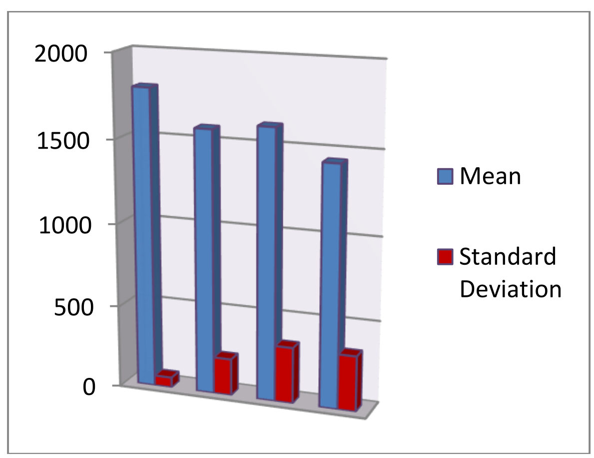

Figure 7: Mean fracture load values in (Newtons) ± S.deviation of the experimental specimens

Table 3: Failure modes index (According to Burke FJ. 1999)

Failure Modes	
Mode 1	Minimal fracture or crack in the crown.
Mode 2	Less than half of the crown is lost.
Mode 3	Crown fracture through midline: half of the crown is lost.
Mode 4	More than half of the crown is lost.
Mode 5	Severe fracture of crown and/or tooth

DISCUSSION

The null hypothesis of this study was accepted since there were no statistically significant differences in the fracture resistance and mode of failure of CAD-CAM monolithic zirconia concerning the occlusal thickness [26, 27]. The fracture resistance of zirconia monolithic crowns was examined, as well as its relationship to the restoration's occlusal thickness. The increase in the restorative material thickness is widely believed to increase its fracture resistance strength, as the physical and mechanical properties are directly related to the thickness [28]. The load-to-failure test and material preparation in the current investigation were essentially carried out following the advice for clinically relevant preclinical experiments [29]. To make the experimental conditions more similar to clinical situations, real teeth were used as abutments. Standardized dies were used to eliminate bias in the evaluation of the effect of occlusal thickness on the fracture resistance of the monolithic zirconia crowns and according to the protocol of recently published studies on thin monolithic zirconia crowns with the same design [9, 10].

In this study, the "monolithic CAD/CAM technique" was chosen as the method for making crowns. This process usually uses high-quality materials with a minimum of flaws compared to the manual veneering process [30].

According to the findings of this study, an occlusal thickness of 0.5 mm was sufficient to withstand regular occlusal loads in the posterior dental areas. The mean fracture resistance values of group 4 (0.5 mm) in this study were (1442.4 N), which is much higher than the average biting forces in the posterior area, which are estimated to be (222-445 N) in the premolars area, and 597-900 N in the area of the molars [13]. Several studies [31, 32] have focused on the method of fracture load testing of the crown. Tinschert et al. [33] found that three-unit FPD zirconia had a fracture resistance greater than 2000 N, whereas Sundh et al. [34] found the fracture load of zirconia is between 2700 N and 4100 N. The fracture load values of monolithic zirconia crowns might potentially be impacted by the mechanical characteristics of the abutment die utilized in the experiment. Previous investigations used various die fabrication processes in fracture load test protocols for single ceramic restorations [35, 36]. Natural tooth abutments offer the advantage of being able to replicate an intra-oral condition, but they also have limitations due to the difficulty of standardizing the specimens. Several variables, such as sample storage, die material, cementation technique, and crosshead speed, could influence static investigation results, explaining the heterogeneity of the data reported in the literature. To imitate the real clinical condition, all specimens were kept wet before testing and luted onto natural teeth with a dual-cure, self-adhesive universal resin cement. The formation of an adhesive "monoblock" Tay and Pashley [37], contributed to increased fracture strength by allowing the cement to act as an elastic stress absorber and compensate for the stiffness of the zirconia, potentially strengthening the restorative system and dissipating occlusal loads across the entire surface of the crowns. Although adhesion between zirconia and RC can be difficult to achieve resin cement may be a first choice [38]. Similarly, to prior studies, the samples were shattered experimentally at a crosshead speed of 1 mm/min. Nordhal et al. [39] reported similar results to those of the present study, suggesting the possibility of reducing crown thickness when fabricating monolithic Y-TZP crowns, reducing the invasiveness of the preparation and saving a valuable amount of dental tissue.

A detailed classification of failure modes was provided by Burke (1999) [25], which classifies fracture failures into five modes, and it became a commonly accepted reference among similar studies. In our study, the predominant fracture mode in all four groups was "cohesive crack" (Burke mode 1). From a clinical viewpoint, the cohesive occlusal microcracks could be polished intraorally without affecting function; they must be regarded as repairable. This inconsistency, however, could be due to their use of resin cement under the crowns, which may have worked as an elastic stress absorber. Adhesive resin cement has the benefit of bonding to the tooth structure and restoration through both chemical and micromechanical bonding. Furthermore, they serve as a buffering layer, absorbing stresses during load application and resulting in higher fracture resistance values [2]. Some earlier investigations validated these findings. Sorrentino et al. [40] found that the predominant failure mode was the "cohesive crack." However, there was a variation between studies regarding this issue; for example, Safe M. et al. [41] reported contradictory results to those of the present study. The authors reported that catastrophic fractures (4 and 5 Burke modes) were the most common fracture modes in all three groups of monolithic crowns; this could be due to differences in design parameters for such studies regarding the chosen abutment's premolar and cementation with glass ionomer cement [40- 42]. Indeed, clinical studies in which ZPC and GIC were used for the cementation of zirconia-based single crowns reported no increased incidence rate of fracture related to the cementation [43, 44]. The inherent material qualities of the crown-cement-abutment complex will have a significant impact on its reaction to loading.

CONCLUSIONs

Within the limitations of this study, the following conclusions were reached for the tested monolithic zirconia crowns:

- The occlusal thickness of CAD-CAM monolithic zirconia had no effect on the restorations regarding either the fracture resistance or the mode of failure.
- The monolithic zirconia crown would still have enough resistance to withstand the regular natural loads even in the posterior oral regions, where the biting forces are at their highest, even if the occlusal thickness was reduced to 0.5 mm.

Conflict of interest

There are no financial, personal, or professional conflicts of interest to declare.

REFERENCES

1. Abd El-Ghany, Ossama Saleh, and Ashraf Husein Sherief. "Zirconia-based ceramics, some clinical and biological aspects." *Future Dental Journal* 2, no. 2 (2016): 55-64.
2. Thompson, Jeffrey Y., Brian R. Stoner, Jeffrey R. Piascik, and Robert Smith. "Adhesion/cementation to zirconia and other non-silicate ceramics: where are we now?" Dental Materials 27, no. 1 (2011): 71-82.
3. .Beuer, Florian, Daniel Edelhoff, Wolfgang Gernet, and Michael Naumann. "Effect of preparation angles on the precision of zirconia crown copings fabricated by CAD/CAM system." Dental materials journal 27, no. 6 (2008): 814-820.

4. Han, Jide, Fei Zhang, Bart Van Meerbeek, Jozef Vleugels, Annabel Braem, and Sylvie Castagne. "Laser surface texturing of zirconia-based ceramics for dental applications: A review." Materials Science and Engineering: C 123 (2021): 112034.
5. Manicone, Paolo Francesco, Pierfrancesco Rossi Iommetti, and Luca Raffaelli. "An overview of zirconia ceramics: basic properties and clinical applications." Journal of Dentistry 35, no. 11 (2007): 819-826.
6. Larsson, Christel, and Per Vult von Steyern. "Five-year follow-up of implant-supported Y-TZP and ZTA fixed dental prostheses. A randomized, prospective clinical trial comparing two different material systems." International Journal of Prosthodontics 23, no. 6 (2010).
7. Larsson, Christel, Per Vult von Steyern, and Krister Nilner. "A prospective study of implant-supported full-arch yttria-stabilized tetragonal zirconia polycrystal mandibular fixed dental prostheses: three-year results." International Journal of Prosthodontics 23, no. 4 (2010).
8. Denry, Isabelle, and J. Robert Kelly. "State of the art of zirconia for dental applications." Dental materials 24, no. 3 (2008): 299-307.
9. Nakamura, Keisuke, Akio Harada, Ryoichi Inagaki, Taro Kanno, Yoshimi Niwano, Percy Milleding, and Ulf Örtengren. "Fracture resistance of monolithic zirconia molar crowns with reduced thickness." Acta Odontologica Scandinavica 73, no. 8 (2015): 602-608.
10. Nakamura, K., A. Harada, T. Kanno, R. Inagaki, Y. Niwano, P. Milleding, and U. Örtengren. "The influence of low-temperature degradation and cyclic loading on the fracture resistance of monolithic zirconia molar crowns." Journal of the mechanical behavior of biomedical materials 47 (2015): 49-56.
11. Nakamura, Keisuke, Mathieu Mouhat, John Magnus Nergård, Solveig Jenssen Lægreid, Taro Kanno, Percy Milleding, and Ulf Örtengren. "Effect of cement on fracture resistance of monolithic zirconia crowns." Acta biomaterialia odontologica Scandinavica 2, no. 1 (2016): 12-19.
12. Ranade, Shantanu R., Youliang Guan, Robert B. Moore, John G. Dillard, Romesh C. Batra, and David A. Dillard. "Characterizing fracture performance and the interaction of propagating cracks with locally weakened interfaces in adhesive joints." International Journal of Adhesion and Adhesives 82 (2018): 196-205.
13. Sun, Ting, Shanyu Zhou, Renfa Lai, Ruoyu Liu, Shuyuan Ma, Zhiying Zhou, and Shao Longquan. "Load-bearing capacity and the recommended thickness of dental monolithic zirconia single crowns." Journal of the mechanical behavior of biomedical materials 35 (2014): 93-101.
14. Lameira, Deborah Pacheco, and Grace M. De Souza. "Fracture strength of aged monolithic and bilayer zirconia-based crowns." BioMed.research international 2015 (2015).
15. Lan, Ting-Hsun, Pao-Hsin Liu, Mitch MC Chou, and Huey-Er Lee. "Fracture resistance of monolithic zirconia crowns with different occlusal thicknesses in implant prostheses." The Journal of prosthetic dentistry 115, no. 1 (2016): 76-83.
16. Ramos, G. Freitas, E. Barbosa Carmona Monteiro, Marco Antonio Bottino, Yu Zhang, and R. Marques de Melo. "Failure probability of three designs of zirconia crowns." The International Journal of Periodontics & restorative dentistry 35, no. 6 (2015): 843.
17. Mitov, Gergo, Yana Anastassova-Yoshida, Frank Phillip Nothdurft, Constantin Von See, and Peter Pospiech. "Influence of the preparation design and artificial aging on the fracture resistance of monolithic zirconia crowns." The Journal of advanced prosthodontics 8, no. 1 (2016): 30-36.
18. Zhang, Yu, Zhisong Mai, Amir Barani, Mark Bush, and Brian Lawn. "Fracture-resistant monolithic dental crowns." Dental Materials 32, no. 3 (2016): 442-449.
19. Batson, Emily R., Lyndon F. Cooper, Ibrahim Duqum, and Gustavo Mendonça. "Clinical outcomes of three different crown systems with CAD/CAM technology." The Journal of prosthetic dentistry 112, no. 4 (2014): 770-777.
20. Moscovitch, Michael. "Consecutive case series of monolithic and minimally veneered zirconia restorations on teeth and implants: up to 68 months." International Journal of Periodontics & restorative dentistry 35, no. 3 (2015).

21. Bindl, A., and W. H. Mörmann. "Marginal and internal fit of all-ceramic CAD/CAM crown-copings on chamfer preparations." Journal of oral rehabilitation 32, no. 6 (2005): 441-447.
22. Euán, Raúl, Oscar Figueras-Álvarez, Josep Cabratosa-Termes, Magí Brufau-de Barberà, and Susana Gomes-Azevedo. "Comparison of the marginal adaptation of zirconium dioxide crowns in preparations with two different finish lines." Journal of Prosthodontics: Implant, Esthetic, and Reconstructive Dentistry 21, no. 4 (2012): 291-295.
23. Kassem, Amr S., Osama Atta, and Omar El-Mowafy. "Fatigue resistance and microleakage of CAD/CAM ceramic and composite molar crowns." Journal of Prosthodontics: Implant, Esthetic, and Reconstructive Dentistry 21, no. 1 (2012): 28-32.
24. El-Guindy, Jylan, Mohamed Selim, and Mona El-Agroudi. "Alternative Pretreatment Modalities with a Self-Adhesive System to Promote Dentin/Alloy Shear Bond Strength." Journal of Prosthodontics: Implant, Esthetic, and Reconstructive Dentistry 19, no. 3 (2010): 205-211.
25. Burke, F. J. T. "Maximising the fracture resistance of dentine-bonded all-ceramic crowns." Journal of Dentistry 27, no. 3 (1999): 169-173.
26. Anusavice, K. J., Kunjan Kakar, and N. Ferree. "Which mechanical and physical testing methods are relevant for predicting the clinical performance of ceramic-based dental prostheses?." Clinical Oral Implants Research 18 (2007): 218-231.
27. Batson, Emily R., Lyndon F. Cooper, Ibrahim Duqum, and Gustavo Mendonça. "Clinical outcomes of three different crown systems with CAD/CAM technology." The Journal of prosthetic dentistry 112, no. 4 (2014): 770-777.
28. Tang, Yu Lung, Jee-Hwan Kim, June-Sung Shim, and Sunjai Kim. "The effect of different cooling rates and coping thicknesses on the failure load of zirconia-ceramic crowns after fatigue loading." The Journal of advanced prosthodontics 9, no. 3 (2017): 152-158.
29. Kelly, J. Robert. "Clinically relevant approach to failure testing of all-ceramic restorations." The Journal of prosthetic dentistry 81, no. 6 (1999): 652-661.
30. Yilmaz, Handan, Cemal Aydin, and Basak E. Gul. "Flexural strength and fracture toughness of dental core ceramics." The Journal of prosthetic dentistry 98, no. 2 (2007): 120-128.
31. Kontonasaki, Eleana, Athanasios E. Rigos, Charithea Ilia, and Thomas Istantsos. "Monolithic zirconia: an update to current knowledge. Optical properties, wear, and clinical performance." Dentistry Journal 7, no. 3 (2019): 90.
32. Kato, Hidetachi, Hideo Matsumura, Takuo Tanaka, and Mitsuru Atsuta. "Bond strength and durability of porcelain bonding systems." The Journal of prosthetic dentistry 75, no. 2 (1996): 163-168.
33. Tinschert, Joachim, Gerd Natt, Walter Mautsch, Michael Augthun, and Hubertus Spiekermann. "Fracture Resistance of Lithium Disilicate--, Alumina-, and Zirconia-Based Three-Unit Fixed Partial Dentures: A Laboratory Study." International Journal of Prosthodontics 14, no. 3 (2001).
34. Sundh, Anders, Margareta Molin, and Göran Sjögren. "Fracture resistance of yttrium oxide partially-stabilized zirconia all-ceramic bridges after veneering and mechanical fatigue testing." Dental Materials 21, no. 5 (2005): 476-482.
35. Schultheis, Stefan, Joerg R. Strub, Thomas A. Gerds, and Petra C. Guess. "Monolithic and bi-layer CAD/CAM lithium–disilicate versus metal–ceramic fixed dental prostheses: Comparison of fracture loads and failure modes after fatigue." Clinical Oral Investigations 17 (2013): 1407-1413.
36. Coelho, P. G., E. A. Bonfante, N. R. F. Silva, E. D. Rekow, and V. P. Thompson. "Laboratory simulation of Y-TZP all-ceramic crown clinical failures." Journal of dental research 88, no. 4 (2009): 382-386.
37. Tay, Franklin R., and David H. Pashley. "Monoblocks in root canals: a hypothetical or a tangible goal." Journal of Endodontics 33, no. 4 (2007): 391-398.

38. Nordahl, Niklas, Per Vult von Steyern, and Christel Larsson. "Fracture strength of ceramic monolithic crown systems of different thickness." Journal of oral science 57, no. 3 (2015): 255-261.
39. Nordahl, Niklas, Per Vult von Steyern, and Christel Larsson. "Fracture strength of ceramic monolithic crown systems of different thickness." Journal of oral science 57, no. 3 (2015): 255-261.
40. Sorrentino, Roberto, Clementina Triulzio, Maria Gabriella Tricarico, Giovanni Bonadeo, Enrico Felice Gherlone, and Marco Ferrari. "In vitro analysis of the fracture resistance of CAD–CAM monolithic zirconia molar crowns with different occlusal thickness." journal of the mechanical behavior of biomedical materials 61 (2016): 328-333.
41. Alzoubi, Safa M., Abdel Ghani Alsahhar, and Ebtisam Alsalameh. "Comparing Fracture Resistance of Monolithic Zirconia Crowns Designed with Three Different Thicknesses: An In Vitro Study." Fogorvosi Szemle 115, no. 4 (2022): 172-177.
42. Jasim, Haider Hasan, Meelad Basil Findakly, Nada Ali Mahdi, and Mustafa Tariq Mutar. "Effect of reduced occlusal thickness with two margin designs on fracture resistance of monolithic zirconia crowns." European Journal of Dentistry 14, no. 02 (2020): 245-249.
43. Örtorp, Anders, Maria Lind Kihl, and Gunnar E. Carlsson. "A 5-year retrospective study of survival of zirconia single crowns fitted in a private clinical setting." Journal of Dentistry 40, no. 6 (2012): 527-530.
44. Tartaglia, Gianluca M., Ernesto Sidoti, and Chiarella Sforza. "Seven-year prospective clinical study on zirconia-based single crowns and fixed dental prostheses." Clinical oral investigations 19 (2015): 1137-1145.