FRACTURE TOUGHNESS AND FRACTURE MODE OF CEMENT-RETAINED VERSUS SCREW-RETRIEVABLE CEMENT-RETAINED IMPLANT-SUPPORTED CROWNS: A PILOT STUDY

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Abstract

The aim of this pilot study was to compare the fracture toughness and fracture mode of cement-retained versus screw-retrievable cement-retained implant-supported monolithic zirconia crowns. Ten implant-supported crowns were made from monolithic CAD/CAM zirconia and equally divided into control and test groups. The control group received cement-retained monolithic zirconia crowns (CR), while the test group received screw-retrievable cement-retained monolithic zirconia crowns (SRCR). The crowns were then bonded to prefabricated Variobase titanium-based abutments with resin luting cement. To simulate the aging process in the oral cavity, all samples were undergone thermal cycling machine. After ageing, each group underwent a single load fracture test to analyze the fracture load, and the fracture mode was evaluated using scanning electron microscopy (SEM). The Mann-Whitney U test was used to compare fracture toughness, and statistical significance was set at $p<0.05$. The mean fracture toughness of CR crowns was 2945.49 ± 511.426 N, while that of SRCR crowns was 2897.82 ± 510.837 N, but the difference was not significant ($U=10$, $p= 0.917$). SEM examination revealed that all failures originated from the fitting surface of the crowns. The titanium-based abutment remained intact in all specimens. Within the limitations of this pilot study, the CR showed higher fracture toughness than SRCR implant crown, but both specimen fracture at six times more than the average maximum bite force of posterior tooth. The presence of screw access in SRCR has affected the fracture mode.

Keywords: Dental Implant, Implant Abutment, Cement Retained, Screw-Retrievable Cement-Retained, Zirconia Crown

Introduction

Dental implants is one of the treatment options for missing teeth for the past four decades (1, 2). Advances in surface technology, surgical techniques, the connection of implant component, the abutment material and ongoing preventative measures to avoid peri-implant diseases have improved dental implant treatment (1-3). Nonetheless, prostheses complications continue to occur, necessitating ongoing research into implant superstructure retention methods (1, 2, 4–6).

Traditionally, implant restorations were either cement or screw retained. Cement-retained (CR) restorations are recommended due to their aesthetic appeal, ease of fabrication, excellent occlusion control, low cost, and passive fit (7–11). Unfortunately, the risk of excess cement during cementation procedure has increased the risk of periimplantitis and perimucositis (12, 13). Furthermore, in the event of screw loosening, retrievability is limited, which may increase the cost of remaking a new crown. Because of this limitation, clinicians have chosen screw retention systems that are easy to retrieve, require less maintenance, and do not require cementation (8, 9). Screw retained restoration, on the other hand, is known for its costly laboratory fabrication, particularly with gold casted abutment, lacks aesthetics and strength due to screw holes traversing the implant crown. Furthermore, when compared to its cemented counterpart, it is more difficult to achieve passive fit. To overcome both limitations, a combination concept known as screw-retrievable cement-retained (SRCR) restoration is used (8, 10, 11).

The SRCR implant crown was frequently connected to a prefabricated titanium abutment due to its light weight, high durability, and favourable soft tissue response (14). The superstructure is cemented extra orally, eliminating the possibility of excess cement. The cement layer also acts as a stress absorber, increasing the fracture toughness of the prosthesis (9, 15). For the fracture toughness of SRCR constructed with metal ceramic, highest fracture load values were recorded for cement-retained designs, followed by SRCR designs (16). Other materials such and monolithic zirconia and lithium disilicate of SRCRs frequently survive and were found to withstand the highest fracture loads (17). Because of these benefits, several protocols for improving SRCR performance were proposed, including preparing the screw access with a diameter of less than 1 mm, creating the screw access holes before sintering, filling the screw access holes rather than leaving them unfilled, and reinforcing the access holes with zirconia predesigned core in veneered restoration to withstand the highest fracture toughness (9, 16).

Regardless of these protocols, it is unclear whether the presence of screw access holes supported with Variobase abutment has affected the fracture load value and structural integrity of the implant crown. Thus, the goal of this study is to compare the fracture toughness and fracture mode of cement-retained versus screw-retrievable cement-retained implant-supported monolithic zirconia crowns. The null hypothesis that there is no difference in these aspects between the two types of implant crowns. This pilot study can help determine the feasibility of the fracture toughness testing method, refine procedures, and provide initial data on the strength characteristics of different crown design.

Materials and Methods

Specimen preparation

10 tissue level implants fixtures (RN 4.8 mm x 10 mm, Institute Straumann AG, Basel, Switzerland) were screwed into acrylic blocks (Figure 1A, 1B & 1C). The elasticity modulus of the acrylic resin used was 12 GPa, which is comparable to human bone (18 GPa) (17). The implant screwed to the first thread in the acrylic resin blocks. Ten implant-supported monolithic zirconia molar crowns were CAD/CAM-fabricated and divided into two groups: five CR crowns for the control group and five SRCR crowns for the test group. The crowns were cemented on implant analogues on a dummy master cast (Figure 2A, 2B & 2C) using type-IV dental stone in accordance with ISO 6873 standards. The scan body was tightened with a self-retaining screw (up to 15 Ncm) and scanned with an intraoral scanner (3Shape TRIOS4 Denmark). The scanning image was also transmitted to the 3Shape program. CR and SRCR monolithic zirconia crowns with 40 µm cement space were fabricated following the manufacturer's guidelines for a full-contour crown thickness.

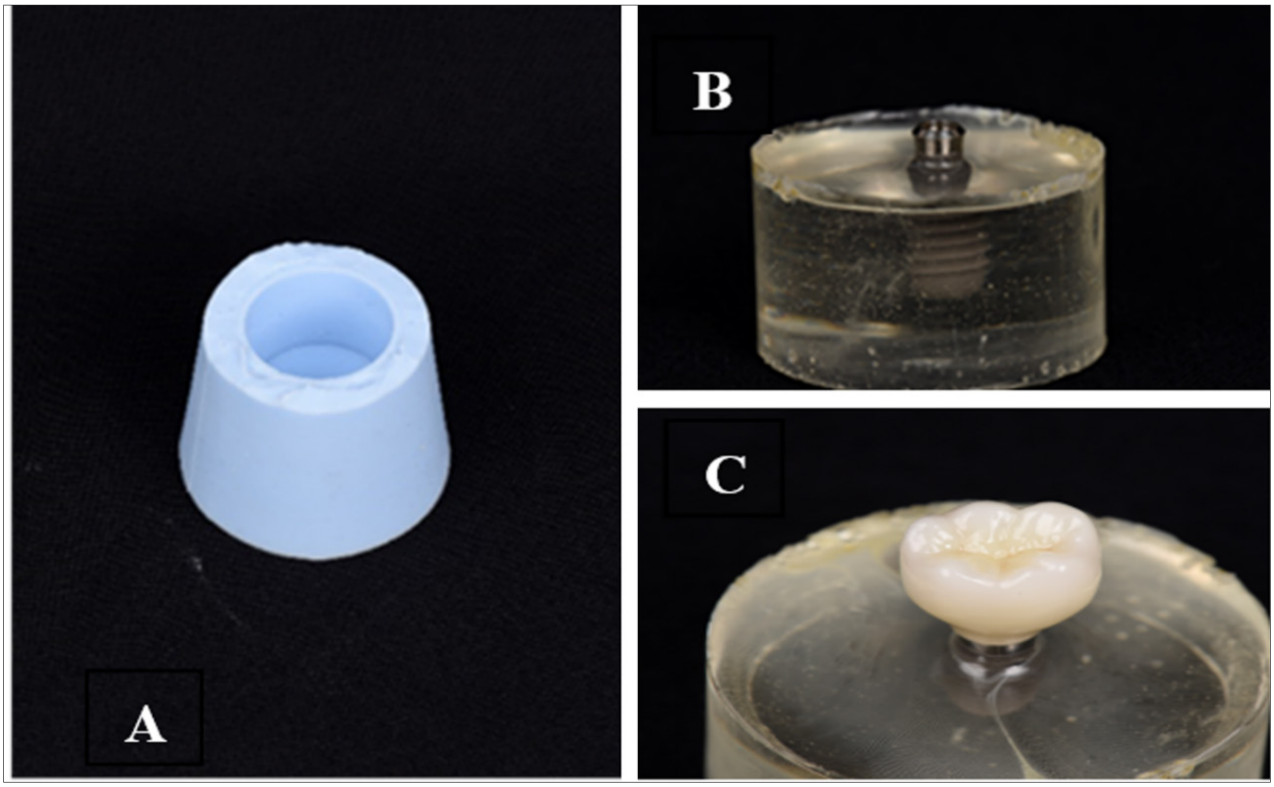

Figure 1: Silicon mould for fabrication of (A) acrylic cylinder block; (B) Implant fixture screwed to the acrylic cylinder block; (C) Crown cemented onto the abutment.

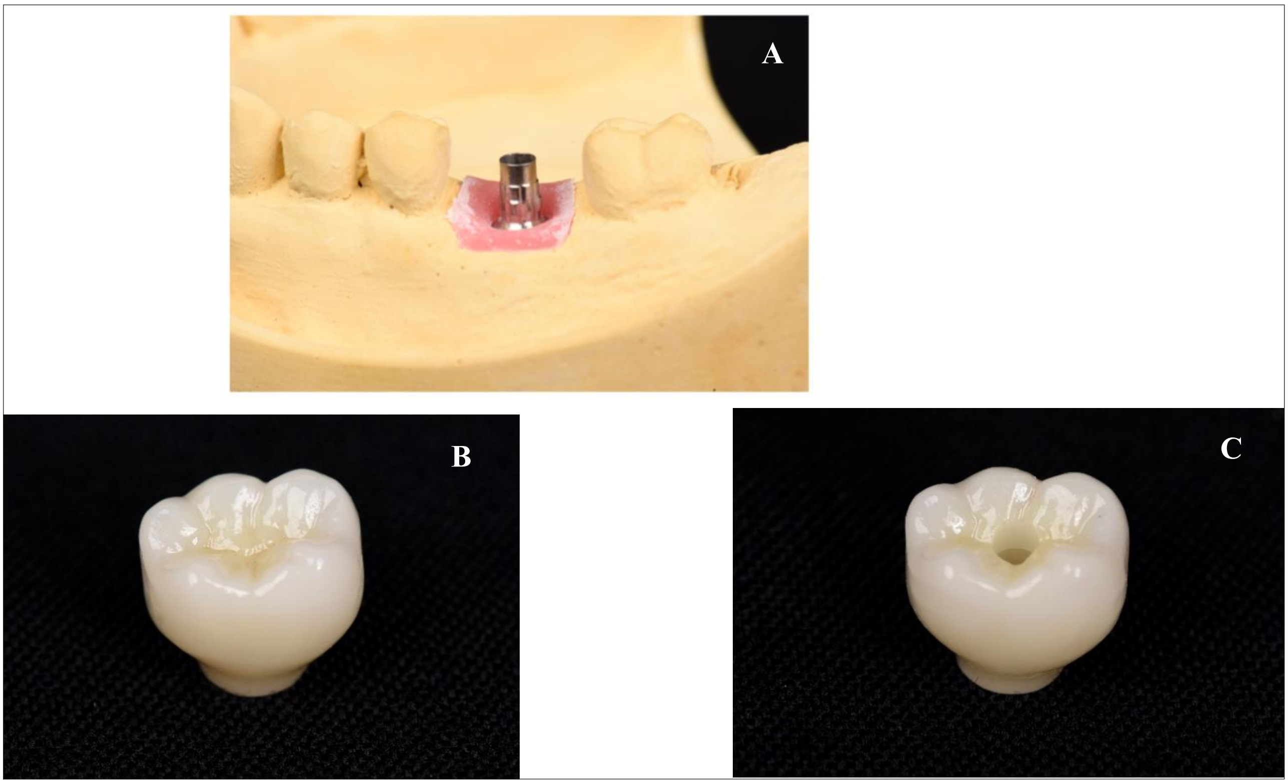

Figure 2: (A) The dummy master cast for scanning and designing the crown. (B) CR monolithic zirconia crown and (C) SRCR monolithic zirconia crown.

The CAD file was sent to a milling machine (Ivoclar Programill PM7, Liechtenstein) for zirconia milling with an IPS e.max ZirCAD pre-sintered zirconia disc. After sintering, the crowns were polished, glazed and the fitting surface air abraded with aluminium oxide (50 µm particle size, 0.5 bar pressure) and cleaned with water- and oil-free compressed air prior to cementation. Variobase® abutments (Institute Straumann AG, Basel, Switzerland) were used for both groups and were manually tightened to the implant analogues up to a torque of 35 Ncm. The crowns were cemented onto the abutments using Rely X™ U200 Adhesive Resin Cement (3M ESPE Oral Care, St. Paul, MN) under a compressive force of 20 N for 15 minutes. The SRCR crowns access holes were sealed with a light-polymerized composite resin.

Specimens testing

To simulate the ageing process in the oral cavity, all specimens were subjected to thermal stress using a thermal cycling machine (Zecttron Automated Thermocyclic Dipping Machine (ATDM)) for 10,000 cycles at 5°C and 55°C with a 30 seconds dwell time (ISO TR 11405) as shown in Figure 3A & 3B. Following the ageing process, each group was subjected to a single load fracture test. To ensure that the load conditions were uniform, a stainless-steel ball with a 6 mm diameter was used (Figure 4). The ball simultaneously contacts three predetermined locations on the occlusal surface of the specimens (mesiobuccal, distobuccal, and mesiolingual points) (16).

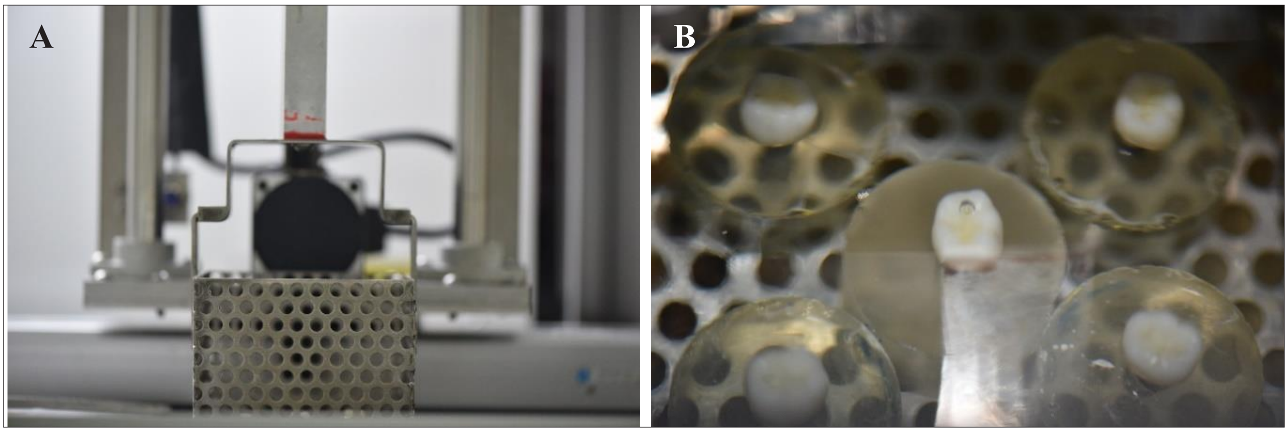

Figure 3: Preparation of the specimen for aging process using thermocycling mechine for 10,000 cycles at 5°C and 55°C with a 30 seconds dwell time.

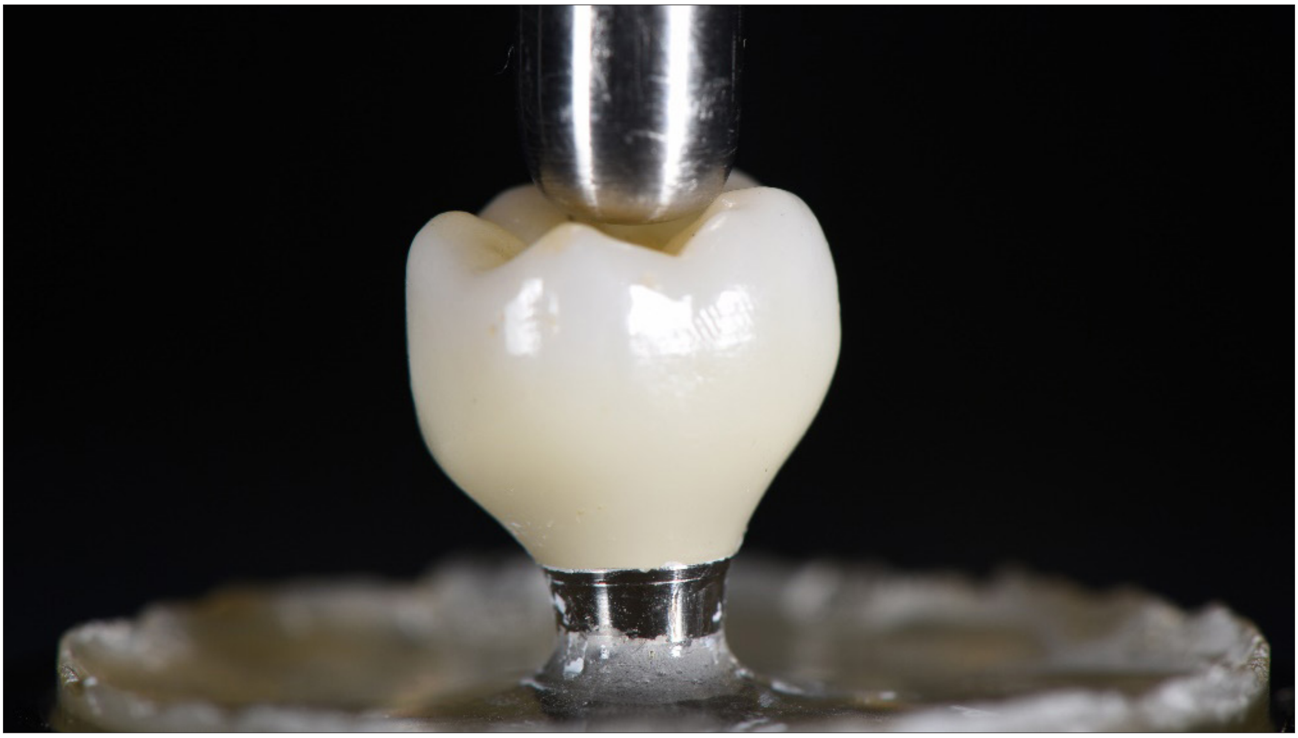

Figure 4: The specimen was subjected to a single load fracture test. To ensure that load conditions are uniform across all specimens, a stainless-steel ball with a 6 mm diameter was used.

Single load until fracture test was utilized to the occlusal surface of the specimens at a 90° angle relative to the horizon using a universal testing machine (Shimadzu Universal Testing Machine) at a crosshead speed of 0.5 mm/minute until failure (Figure 5A & 5B). A load decrease of 10% or more, as measured by the testing machine, was considered a failure. This change in load was detected automatically by the computer software of the testing machine (18)screw access opening placed in the center of the occlusal surface; Group 2 (Screw-retained; occlusal surface buccolingual width=5 mm.

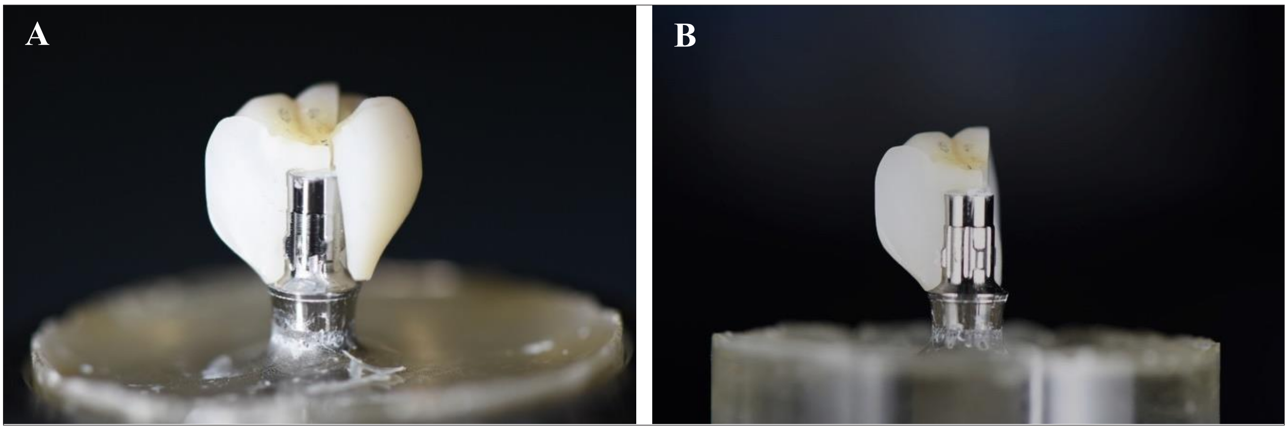

Figure 5: The specimens after a single load until fracture test applied to the occlusal surface of the specimens: (A) CR shows less than 50 % crown fracture, (B) SRCR shows more than 50 % crown fracture after testing.

After load fracture test, the fracture specimens were analysed under a Scanning Electron Microscope (Supra 55VP, Zeiss). Prior to the scanning procedure, all specimens were sputter-coated and the acceleration voltage (EHT) adjusted to 10.0 kV. The fracture modes were determined by observing the remaining restorative material: (A) less than 50% crown remaining, (B) 50-75% crown remaining, and (C) more than 75% crown remaining.

Data analysis

The Statistical Software Package for Social Science (24.0) was used to analyse the data (SPSS Inc, Chicago, USA). Mann-Whitney U test was used to analyse the failure load, and the threshold for determining statistical significance was set at P=0.05. Descriptive analysis was carried out to determine the origin and mode of fracture.

Results

The mean fracture toughness of the cement-retained monolithic zirconia crowns was 2945.49 ± 511.43 N, while that of screw-retrievable cement-retained crowns was 2897.82 ± 510.84 N. (Table 1). Table 2 shows the difference in fracture toughness between the two groups. This study used Mann-Whitney U test statistics (10) and Asymp. sig. (2-tailed) to reject or fail to reject the null hypothesis. Since in our example, p=0.917, > 0.05, we fail to reject the null hypothesis and conclude that there is no difference in the fracture strength between CR and SRCR group. In terms of fracture mode, the CR group performed slightly better than the SRCR group; more crown material remains intact (Table 3). The fracture origin was also identified in this study, which is at the fitting surface or at the refining surface of the crown. Observing the hackle lines on the surface of the ceramic enabled the identification of this failure (Figure 6). These lines radiated from the fracture origin and perpendicular to the crack progression (19). From the SEM analysis, cracks originated from the fitting surface for both types of crowns and for the SRCR group, it seems to start from the screw access hole. (Figure 7A, 7B,7C & 7D)

Table 1: Mean fracture load (Newton) and standard deviation of group CR and SRCR

	Sample Size	Mean Fracture Load (N)	Standard Deviation (N)
CR	2	2945.49	± 511.426
SRCR	2	2897.82	± 510.837

Table 2: The table shows the significant difference in test statistics.

Test Statistics[a]	
	Fracture value
Mann-Whitney U	12.000
Wilcoxon W	27.000
Z	-.104
Asymp. Sig. (2-tailed)	.917
Exact Sig. [2*(1-tailed Sig.)]	1.000[b]

a Grouping Variable: Type of crown

b Not corrected for ties.

Table 3: Percentage fracture modes of various groups

Experimental Group	Sample Size (N=10)	Percentage fracture mode of various groups
CR	5	< 50 %= 40% (n=2) 50-75%= 20% (n=1) > 75%=40 (n=2)
SRCR	5	< 50 %= 60% (n=3) 50-75%= 20 % (n=1) > 75%= 20% (n=1)

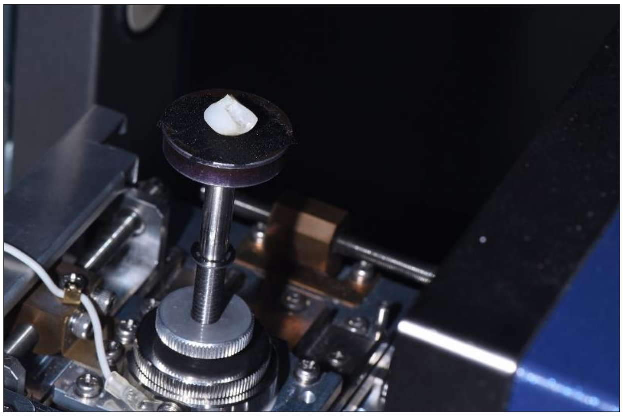

Figure 6: The specimens were analysed using Scanning Electron Microscopy (SEM) to evaluate the fracture surfaces for identify the fracture mode of each specimen after a single load until fracture test.

Discussion

The purpose of this pilot study was to compare the fracture toughness and fracture mode of two crown designs: cement-retained (CR) and screw-retrievable cement-retained (SRCR) for implant supported single crown. CR demonstrated higher fracture toughness but not significantly different to SRCR crowns, probably due to the small sample size. Previous studies have shown that the presence of screw access affected the structural continuity of the ceramic and bond strength causing lower fracture load value and chipping risk that was not seen in the cemented counterparts (8–11, 20)advantages and disadvantages of the different retention mechanisms, the retention provided, retrievability, provisionalization, esthetics and clinical performance, including failures and complications. The results of recently published systematic reviews on this topic are discussed and an overview is provided. A decision tree is presented to facilitate the clinical selection of the retention type. This overview concludes that the choice of retention type (screw retained or cement retained. The timing of preparation of the screw access hole itself either before or after sintering could potentially impact the fracture strength of SRCR crown (21). It was recommended to prepare the screw access in blue phase prior to crystallization to avoid cracks in the restoration. Grinding zirconia to create access hole after sintering may cause phase transformation in zirconia microstructure (16).

The fracture toughness value recorded for both groups of monolithic crowns was close to 3000 N, which far exceeded the posterior region of the mouth's mean masticatory force of 200 to 540 N (22). This finding is consistent with previous studies that show monolithic zirconia is suitable for implant-supported crowns in the posterior region (1–3)that is, survival and complication rates of zirconia-ceramic and/or monolithic zirconia implant-supported fixed dental prostheses (FDPs.

On the hand, the fracture mode varies with the CR group had more than 75% of crown remaining, while most of SRCR crown had less than 50% of crown remaining. The descriptive analysis of the result indicates the variety of failure mode with weakness is related to the crown design. This result also recorded that catastrophic failure only occurred when load was exceeding 2157.77 N. However, the high fracture load in monolithic ceramic restoration has raised concern on stress around the cervical peri-

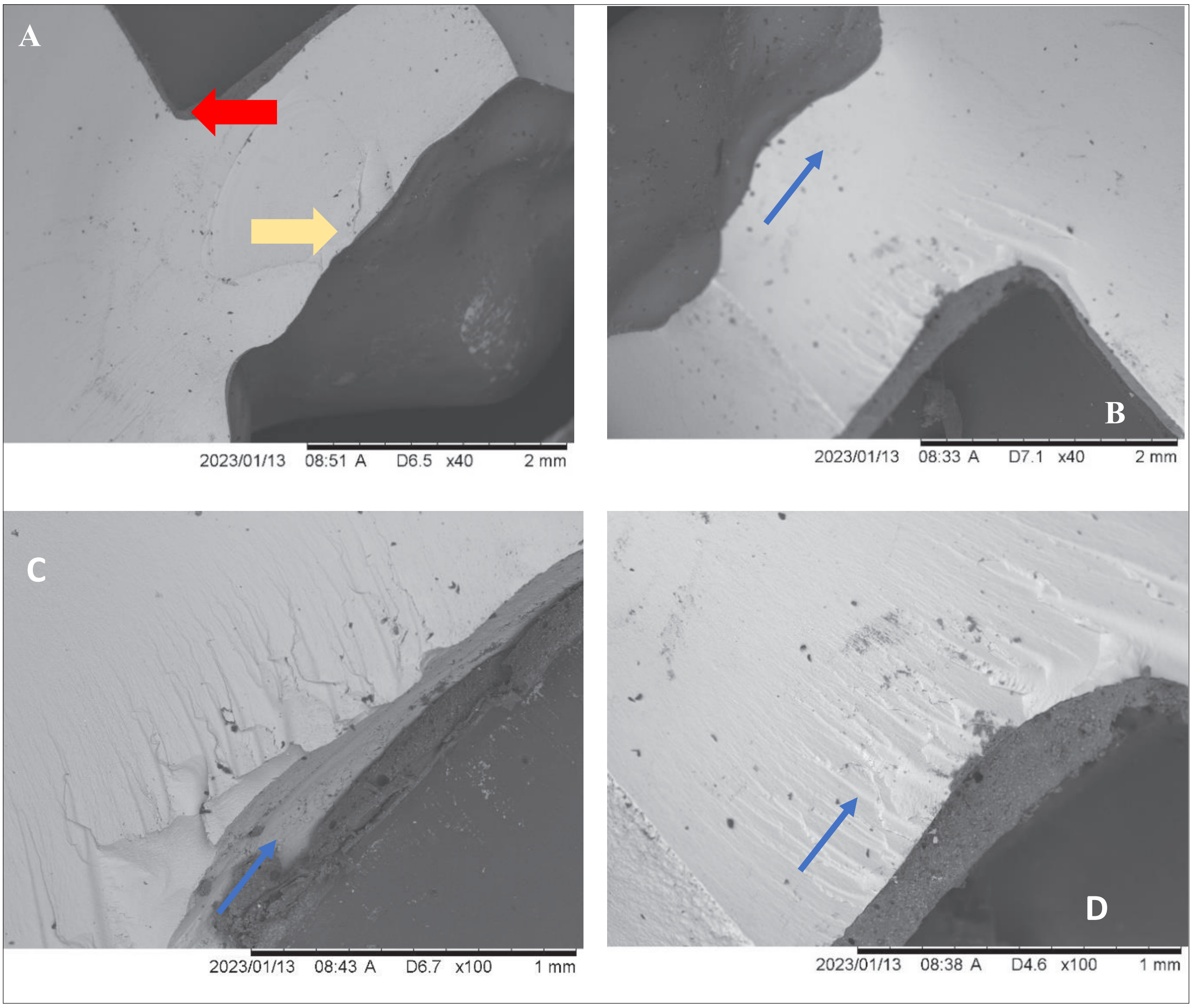

Figure 7: The specimens were analysed using Scanning Electron Microscopy (SEM) under x40 magnification **(A)** and under x100 magnification **(B)**. The red arrow in the figure 7(A) is the polishing surface of the crown and the yellow line is the fitting surface of the crown. The blue line in figure 7(B) is the hackle lines on the surface of the ceramic enabled the identification of crack propagation and the failure's origin. **(C)** The fracture origin came from the fitting surface originating from the screw access on MZV and it appears that the stress or strain concentration around the screw access hole may have led to the initiation and propagation of cracks. **(D)** In MCV, SEM images revealed that all sample groups displayed fractures originating from the fitting surface of the crowns and not extend to occlusal surface.

implant bone, causing crestal bone resorption (23). Having various compromised situation such as short implant, bruxism or narrow ridge, clinician should know that certain type of material may have high fracture toughness, but may influence stress distribution that would affect the biological and mechanical complication of implant treatment. Therefore, it was suggested to use low modulus of elasticity such as Polymer Infiltrated Ceramic Network (PICN) that offer better stress distribution and have comparable fracture toughness. Furthermore, PICN has higher damaged tolerance after adjustment of implant restoration justifying the lower impact of crack degradation compared to ceramic material (24). As various alternative materials is available, more studies needed to prove the best and most stable implant restorative material (25).

As mentioned, in the present study resulted with 100% survival of Ti-base abutment. This prefabricated abutment has showed high mechanical stiffness and offers an excellent prosthetic unit of implant restoration regardless of material type (26). Since it is a trend to use titanium based abutment, it is interesting to note that this prefabricated abutment is not only used as one piece, but also as two piece where coping ceramic is used as customized abutment design (8, 27). While the Variobase design incorporates a retention slot, the specific impact of this feature on the crack propagation is unclear. In this current study, an interesting observation was made regarding the origin of cracks in the examined samples. In the SRCR group, the cracks were found to originate from the fitting surface extending into the screw access area. It appears that the load concentration around the screw access hole may initiate the propagation of cracks from abutment screw access to occlusal surface. On the other hand, in the CR group, SEM images revealed that all sample groups displayed fractures originating from the fitting surface and does not extend to the occlusal surface. As the abutment survived under fracture load for both types of restoration, the prefabricated titanium based with mechanical features such as groove or slot is projected to improve retention between screw or cemented crown (28). With this limited study, the result from SEM show that the crown design has influence the crack origin but not related to the abutment. However, inferring whether type of abutment design is difficult since only one type of abutment is used. Therefore, further study should consider to investigate with more variables such as abutment height and abutment surface whether flat or with slots to ensure their long-term performance.

Due to the nature of this study, the result should be clarified with caution. Although it is in vitro test, our pilot study has included thermocycling and analysis of SEM to produce information of fracture toughness and fracture mode from different crown design. This pilot study encouraged standardized sample preparation for a control testing method to measure fracture toughness and fracture mode thru stainless steel ball. This encouraged the feasibility of testing procedures, refine the methodology and to evaluate the durability of the CR and SRCR implant crown. In addition, the pilot study acts as a critical preparatory phase and to confirm the necessary sample size for statistical significance and mitigate potential issues Yet, limitation existed by not having larger sample size and only single loading. Therefore, further clinical controlled clinical studies are necessary to validate the laboratory findings.

Conclusion

Based on this limited sample, the CR showed higher fracture toughness than SRCR implant crown, load required to fracture it is approximately 6 times the average maximum bite force of a molar. For SRCR, the presence of screw access in monolithic zirconia restoration affected the fracture mode with less crown remaining after loading. The SEM fractographic analysis conducted in this study revealed that the presence of a screw access has influence crack propagation from the fitting surface of the crown. Nonetheless,

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Competing interests

The authors declare that they have no competing interests.

Ethical Clearance

Not applicable.

References

1. Sailer I, Strasding M, Valente NA, Zwahlen M, Liu S, Pjetursson BE. A systematic review of the survival and complication rates of zirconia-ceramic and metal-ceramic multiple-unit fixed dental prostheses. Clin Oral Implants Res. 2018; 29(March):184–98.
2. Pjetursson BE, Thoma D, Jung R, Zwahlen M, Zembic A. A systematic review of the survival and complication rates of implant-supported fixed dental prostheses (FDPs) after a mean observation period of at least 5 years. Clin Oral Implants Res. 2012; 23(SUPPL.6):22–38.
3. Amal M, Wahab A, Yusof EM, Ahmad R, Salleh MZ, Kek TL. Peri-implant Bone Healing : Its Basic Osteogenesis and Biomarkers. Malays J Med Health Sci. 2022; 18(6):324–31.
4. Jivraj S, Chee W. Rationale for dental implants. Br Dent J. 2006; 200(12):661–5.
5. Pjetursson BE, Valente NA, Strasding M, Zwahlen M, Liu S, Sailer I. A systematic review of the survival and complication rates of zirconia-ceramic and metal-ceramic single crowns. Clin Oral Implants Res. 2018; 29(January):199–214.
6. Wong CKK, Narvekar U, Petridis H. Prosthodontic Complications of Metal-Ceramic and All-Ceramic, Complete-Arch Fixed Implant Prostheses with Minimum 5 Years Mean Follow-Up Period. A Systematic Review and Meta-Analysis. J Prosthodont. 2019; 28(2):e722–35.
7. Al-Omari WM, Shadid R, Abu-Naba'a L, Masoud B El. Porcelain fracture resistance of screw-retained, cement-retained, and screw-cement-retained implant-supported metal ceramic posterior crowns. J Prosthodont. 2010; 19(4):263–73.
8. Wittneben JG, Joda T, Weber HP, Brägger U. Screw retained vs. cement retained implant-supported fixed dental prosthesis. Periodontol 2000. 2017; 73(1):141–51.
9. Malpartida-Carrillo V, Tinedo-López PL, Ortz-Culca F, Guerrero ME, Amaya-Pajares SP, Özcan M. Fracture Resistance of Cement-retained, Screw-retained, and Combined Cement- and Screw-retained Metal-ceramic Implant-supported Molar Restorations. J Contemp Dent Pract. 2020; 21(8):868–73.
10. Rajan M, Gunaseelan R. Fabrication of a cement- and screw-retained implant prosthesis. J Prosthet Dent. 2004; 92(6):578–80.
11. Hebel KS, Gajjar RC. Cement-retained versus screw-retained implant restorations : Achieving optimal occlusion and esthetics in implant dentistry. J Prosthet Dent. 1997; 77(1):28-35.
12. Pesce P, Canullo L, Grusovin MG, De Bruyn H, Cosyn J, Pera P. Systematic review of some prosthetic risk factors for periimplantitis. J Prosthet Dent. 2015; 114(3):346–50.
13. Staubli N, Walter C, Schmidt JC, Weiger R, Zitzmann NU. Excess cement and the risk of peri-implant disease – a systematic review. Clin Oral Implants Res. 2017; 28(10):1278–90.
14. Kofron MD, Carstens M, Fu C, Wen HB. In vitro assessment of connection strength and stability of internal implant-abutment connections. Clin Biomech. 2019; 65(Nov 2018):92–9.
15. Derafshi R, Farzin M, Taghva M, Heidary H, Atashkar B. The Effects of New Design of Access Hole on Porcelain Fracture Resistance of Implant-Supported Crowns. J Dent (Shiraz, Iran). 2015; 16(1 Suppl):61–7.
16. Saboury A, Mahshid M, Tabatabaian F, Moghadam L. Effect of screw access hole design on the fracture resistance of implant-supported zirconia-based

restorations. J Esthet Restor Dent. 2018; 30(6):545–50.
17. 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(1):65–72.
18. Torrado E, Ercoli C, Mardini M Al, Graser GN, Tallents RH, Cordaro L. A comparison of the porcelain fracture resistance of screw-retained and cement-retained implant-supported metal-ceramic crowns. J Prosthet Dent. 2004; 91(6):532–7.
19. Moráguez OD, Wiskott HWA, Scherrer SS. Three- to nine-year survival estimates and fracture mechanisms of zirconia- and alumina-based restorations using standardized criteria to distinguish the severity of ceramic fractures. Clin Oral Investig. 2015; 19(9):2295–307.
20. Lee H, Jo M, Noh G. Biomechanical effects of dental implant diameter, connection type, and bone density on microgap formation and fatigue failure: A finite element analysis. Comput Methods Programs Biomed. 2021 Mar; 200:105863.
21. Pereira GKR, Silvestri T, Camargo R, Rippe MP, Amaral M, Kleverlaan CJ, et al. Mechanical behavior of a Y-TZP ceramic for monolithic restorations: Effect of grinding and low-temperature aging. Mater Sci Eng C. 2016; 63:70–7.
22. Ferrario VF, Sforza C, Zanotti G, Tartaglia GM. Maximal bite forces in healthy young adults as predicted by surface electromyography. J Dent. 2004; 32(6):451–7.
23. De Kok P, Kleverlaan CJ, De Jager N, Kuijs R, Feilzer AJ. Mechanical performance of implant-supported posterior crowns. J Prosthet Dent. 2015; 114(1):59–66.
24. Facenda JC, Borba M, Corazza PH. A literature review on the new polymer-infiltrated ceramic-network material (PICN). J Esthet Restor Dent. 2018; 30(4):281–6.
25. Yuan JCC, Sukotjo C. Occlusion for implant-supported fixed dental prostheses in partially edentulous patients: A literature review and current concepts. J Periodontal Implant Sci. 2013; 43(2):51–7.
26. Joda T, Huber S, Bürki A, Zysset P, Brägger U. Influence of Abutment Design on Stiffness, Strength, and Failure of Implant-Supported Monolithic Resin Nano Ceramic (RNC) Crowns. Clin Implant Dent Relat Res. 2015; 17(6):1200–7.
27. Zhang M, King D, Ho L, Pelekos G, Fok MR. Clinical performance of implant-supported single hybrid abutment crown restoration : A systematic review and meta-analysis. J Prosthodont Res. 2024; 68(1): 63-77.
28. Favasuli L, Mascarenhas PS, Mauricio P. Laboratory Fracture Resilience of Hybrid Abutments Used in Oral Rehabilitation: A Systematic Review. J Funct Biomater. 2022; 13(3):120.