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In Vitro Evaluation of the Fracture Strength of Four Contemporary CAD/CAM Resin Based Composite Materials Used in the Fabrication of Implant Supported Dental Crowns

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ABSTRACT

Introduction: To compare the fracture strengths of crowns cemented to implant abutments using four monolithic resins based composite materials.

Methods: For the monolithic crowns, 40 titanium implant abutments were attached on implant analogs, split into four groups of ten each. The groups were divided as follows: BRILLIANT Crios Resin-Based Composite Block (RBC) (COLTENE, Switzerland), VITA ENAMIC Polymer-Infiltrated Ceramic Networks (PICNs) (VITA Zahnfabric, Germany), GRANDIO Blocs Resin-Based Composite Block (RBC) (VOCO GmbH, Germany), Tetric CAD Resin-Based Composite Block (RBC) Tetric CAD (Ivoclar Vivadent, Liechtenstein). The abutments of all groups were scanned then crowns design was done with InLab software, then milled using InLab MC XL milling unit. Airborne-particle abrasion (Al_2O_3, 50 μm) was used on the external surfaces of the implant abutments. Then, saline containing adhesive was applied. The inner surfaces of each crown were surface treated as directed by the manufacturer, and then were cemented with a dual cured adhesive resin (RelyXTM Ultimate, 3M ESPE, Germany). Then stored in distilled water in laboratory incubator at 37°C for 1 week. After that thermo cycling was done at 5 to 55°C, 1minute cycle time for total 500 cycles. The crowns then were subjected to compressive axial loading until rupture at a 1 mm/min crosshead speed. In a universal testing machine (LARYEE, China), one-way ANOVA and LSD tests was then used to examine the data.

Results: The highest mean value of fracture strength was obtained by GRANDIO Blocs (4.32 kN), followed by Tetric CAD (3.89 kN), BRILLIANT Crios (3.78 kN), VITA ENAMIC (3.01 kN) respectively, indicating statistically significant differences ($p<0.01$) among the different groups. Regarding the fracture mode, the majority of samples of all groups showed crown fracture and total deboning.

Conclusion: Differences related to chemical composition and microstructure of the studied hybrid ceramics and resin composite CAD/CAM materials resulted in statistically significance difference in the fracture strength of the implant supported crowns.

Keywords: CAD/CAM, Fracture Strength, Implant, Resin Based Composite, Nano Fillers.

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INTRODUCTION

Superior esthetic and biocompatibility of all ceramic restorations increased their popularity[1] but low mechanical properties of early ceramic materials raised a concern about their clinical application[2]. With the advancement of the ceramic materials monolithic, chair side restoration became the preferred choice for restorations to overcome one of the most common reasons of failure which is chipping of the veneering layer and to deduct from the time of fabrication and enabling single visit crown restorations[3].

Materials used in crowns and prosthetic components must have enough strength to resist forces during chewing, these forces may reach in average to 629N in males and 526N in female in the posterior regions of the jaw, this is essential to the success of dental implants[4] in implant supported restorations Resin matrix, Glass matrix, and Polycrystalline ceramics are the CAD/CAM materials that can be used.

Occlusal overloading is increased with implant supported crowns as opposite to tooth supported crowns because no periodontium is present between implant and bone. This must be taken into account while choosing the appropriate materials. However, unlike natural teeth, where mastication pressure is transferred to the bone surrounding the periodontal ligament through the periodontal mechanoreceptors in the periodontal ligament, dental implants do not have these sensory receptors[5].

High strength ceramics have high resistance to fracture and therefore can tolerate force peaks[6]; nevertheless, because of their high stiffness, these stresses may be transferred from the restoration to the supporting structure[7]. As opposed to this, RBC and PICN mainly with nano sized inorganic filler and lower elasticity moduli may be able to absorb more energy and dampen applied loads, minimizing their impact on the bone-implant contact as a result[8].

Implant supported composites crowns have stress absorption qualities because the elasticity modulus of CAD/CAM composites is comparable to that of dentin[8]. Low brittleness, increase tolerance to damage and less marginal chipping makes composites a very well suited material to CAD/CAM machining[9]. They also have smoother milling margins, and can be milled to smaller thicknesses[8]. Blocks of CAD/CAM composite for single visit applications are made more acceptable because of the lack of firing step intended for crystallization or staining of ceramic.

In clinical practice, hybrid CAD/CAM composite crowns have been frequently used since 2014. Concerns have been raised, however, about CAD/CAM composite resin strength used in posterior region due to a lack of studies looking into the subject[10]. This necessitates further research into the CAD/ CAM composite fracture strength, particularly when they are used in implant-supported restorations.

MATERIAL & METHODS

Forty implant abutment analogs (n=40' Dentium, titanium grade IV, implant diameter 4.5 mm, implant length 12mm) and stock Titanium abutments (length 5.5mm, diameter 6.5mm) have been selected and screwed into the analogs using a driver according to manufacturer's instruction (30 N), then were vertically positioned in mix of cold cure acrylic at dough stage[11,12]. Analogues mounting were done to within 2 mm apical abutment finish line Figure 1[13].

The 40 implants were distributed into 4 groups of 10 implants each. Monolithic crowns were made from different CAD/CAM composite Figure 2 and the used block shown in Table 1.

InEos X5 (Dentsply Sirona) digital lab scanner was used to scan all the abutments followed by designing of the crowns in the In Lab Sirona (version 18.1) software. The restoration parameters were according to manufacturer recommendation. The milling was done with an In Lab MC XL milling machine.

Light cure composite (Tetric® N-Ceram, Ivoclar Vivadent) was used to seal screw opening for all abutments[14]. Then the Airborne particle abrasion (Al_2O_3, 50 μm) by intraoral sandblaster (KaVo RONDOflex Plus 360, KaVo Dental GmbH, Germany) was used on the exterior surfaces of implant abutments. Then, saline containing adhesive (single bond universal 3M ESPE) was applied[11].

The inner surface of the crowns was treated according to manufacturer instructions as in Table 2, followed by cleaning for 5 minutes in an ultrasonic cleaner.

After that the crowns were bonded on their respective abutments Figure 2 using dual cured adhesive resin cement (RelyXTM Ultimate, 3M ESPE, Germany). Then loaded with a 5Kg (50 N) vertical static load using a specially built loading device to prevent rebounding Figure 3[15]. Then light cured for 20 second per surface according to manufacturer's instruction.

Then in a laboratory incubator all the samples were stored in 37°C distilled water for one week[11]. Before mechanical testing, to simulate oral environment thermo cycling was done to all samples, using an automatic thermo cycling device at 500 cycles (5 to 55°C, Dwell times: 25 sec., lag time 10 sec.)[15].

Compressive axial loading until rupture was applied to all samples through stainless steel rod with a 5-mm diameter sphere head, at a 1mm/min speed. Utilizing a computer controlled electronic Universal Testing Machine (LARYEE Universal testing machine). One millimeter of rubber was used between the crown and the occluding rod to relive the stress[16].

Each sample then was examined visually using a digital microscope to determine the mode of fracture, fracture mode classification for implant supported restorations by Elsayed and colleagues was used[17] as shown in Table 3. At a significance level of 0.05, 1 way ANOVA and LSD post-hoc tests were used to statically evaluate the data.

Figure 1: Implant assembly mounting.

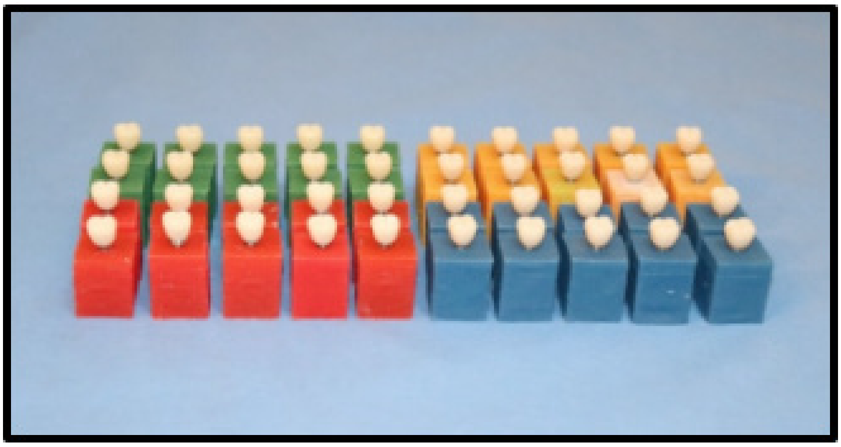

Figure 2: Sample Groups: TC: Tetric CAD, BC: BRILLIANT Crios, VE: VITA ENAMIC, GB: Grandio Blocs.

Table 1. Manufacturer and composition of the CAD/CAM resin-based composite blocks.

CAD/CAM resin-based composite blocks	type	composition	
		Organic	Inorganic fillers
VITA ENAMIC (VITA Zahnfabric, Germany)	PICN	(UDMA), (TEGDMA)	(~ 86 % by weight)
BRILLIANT Crios (COLTENE, Switzerland)	RBC	bis-Gma, bis-EMA TEG-DMA	(70.7% by weight)
Grandio Blocs (VOCO GmbH, Germany)	RBC	UDMA, DMA	(86 % by weight)
Tetric CAD (Ivoclar Vivadent, Liechtenstein)	RBC	Bis-GMA, Bis-EMA, TEGDMA, UDMA.	(71.1% by weight

Table 2. Conditioning protocol of the restorations.

Material	Surface-treatment
VITA ENAMIC	hydrofluoric acid, 60-second
BRILLIANT Crios	Sandblasted 50 μm Al2O3, 1.5 bar, 60-second
Grandio Blocs	Sandblasted 50 μm Al2O3, 1.5 bar, 60-second
Tetric CAD	Sandblasted 50 μm Al2O3, 1.5 bar, 60-second

Figure 3: Customized loading device (5000 g).

Table 3. Mode of fracture classification.

Mode of Fracture	Description
Code 1	Crown fracture
Code 2	Crown fracture + total debonding
Code 3	Crown indentation
Code 4	Crown + abutment fracture
Code 5	Screw fracture
Code 6	Implant/analogs deformation

Table 4. Fracture strength values of the different groups measured in KN.

Groups	N.	Mean	Std. Deviation	Maximum	Minimum
Tetric CAD	10	3.89	.22	4.27	3.54
Enamic	10	3.01	.6	3.63	1.66
Grandio Blocs	10	4.32	.5	5.12	3.52
BRILLIANT Crios	10	3.78	.56	4.58	2.96
Total	40	3.75	.67	5.12	1.66

Table 5. Results of one-way ANOVA test.

ANOVA	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	9.022	3	3.007	12.602	.001
Within Groups	8.591	36	.239		
Total	17.613	39			

Table 6. Results of Post hoc tests.

Fracture strength (kN)				
Study group				
Tetric CAD Mean ± SD	Enamic Mean ± SD	Grandio Blocs Mean ± SD	BRILLIANT Crios Mean ± SD	P - Value
3.89 ± 0.22	3.01 ± 0.6	-	-	0.001
3.89 ± 0.22	-	4.32 ± 0.5	-	0.065
3.89 ± 0.22	-	-	3.78 ± 0.56	0.623
-	3.01 ± 0.6	4.32 ± 0.5	-	0.001
-	3.01 ± 0.6	-	3.78 ± 0.56	0.001
-	-	4.32 ± 0.5	3.78 ± 0.56	0.022

RESULTS

The reported mean of fracture strength was the highest in Grandio Blocs group (4.32 kN.) followed by Tetric CAD (3.89 kN.), BRILLIANT Crios (3.78 kN.) groups respectively. Whereas the lowest mean of the fracture strength value was the Enamic group (3.01 kN) as shown in Table 4**.**

The ANOVA test showed a statistically significant difference at (p 0.01) between the groups as shown in Table 5.

Post Hoc Test (LSD) test was performed for comparisons between different pair of the groups to examine the source of difference and showed that mean of maximum load to fracture was significantly higher ($P < 0.05$) in Grandio Blocs group than that in Vita Enamic and BRILLIANT Crios groups. It was significantly higher ($P = 0.001$) in Tetric CAD group than that in Enamic (Vita) group; and significantly higher ($P= 0.001$) in BRILLIANT Crios group than that in Enamic (Vita) group. No significant differences detected in mean of maximum load to fracture between Tetric CAD group and both of Grandio Blocs and BRILLIANT Crios groups as shown in Table 6.

DISCUSSION

A notable outcome of this study is that, despite statistically significant differences in the fracture strength between tested groups, the mean fracture strength value was more than the maximum masticatory force in the second molar area (900 N) which came in agreement with former studies which found RBC and Enamel fracture strength surpassed the maximum biting force for single unit implant supported restorations[11,12]. From one perspective, the titanium stock abutment design offered sufficient material bulk to withstand the load, which led to this result. On the other hand, the implementation of an adhesive cementation procedure with surface pretreatment of the materials in accordance with their manufacturer's recommendations, may account for the result.

The null hypothesis was rejected as different CAD/CAM composite blocks have recorded different fracture strength. Fracture strength was valued between 1.66 kN to 5.12 kN for the tested composite blocks.

With respect to recorded mean fracture strength, the Grandio Blocs (4.32 kN. ± 0.5 kN. SD) were statistically significantly higher than the Brilliant Crios and Vita Enamic groups, while it was higher than Tetric Cad group but there was no statistical significance.

It was observed in this study that there was a significant difference between Grandio and Brilliant Crios in fracture strength and this might be related to the high filler content in Grandio blocks, which consist of 86% Nano hybrid ceramic filler compared to Brilliant Crios with lower filler loading which consist of 70% of glass and amorphous silica. In accordance with prior research, which found that materials with higher filler contents had higher fracture strength, filler particles halt crack propagation by deflecting crack and by bridging effect, and thus increasing the strength of the restorative materials[18]. Although, the resulted difference in the mechanical properties of high filler content (Grandio blocs) and lower filler content (Crios) came in disagreement with Hafez and collogues who observed no difference between the same tested material, and I think this variation in the results might be relating to using natural tooth as substrate and different restoration design[19].

The fracture strength of the resin-based composite blocks investigated in this study was found to be higher in blocks that contain UDMA in the polymer matrix (such as Grandio blocs and Tetric Cad) when compared to blocks that contain BIS-GMA polymer matrix (such as Brilliant Crios), which has been confirmed in previous studies[20,21]. No statistical significant difference between Grandio blocs and Tetric Cad groups was found and this result came in agreement with Rosentritt and colleagues who used these CAD/CAM composite blocks but different supporting structure different supporting structure[22].

Another finding in this study that the Enamic group recorded the lowest mean in the fracture strength (3.01 kN. ± 0.6 kN. SD) which might be related to the difference in the structure between (PICN) and (RBC) which is responsible for the difference in its mechanical properties. It was found that (PICN) under loading have plastic deformation because of their polymer phase and their ceramic network which is 86% of its weight which increase their hardness and brittleness[23], while (RBC) with Nano fillers have a higher fraction of resin matrix thus higher fracture loads and superior longevity[13].

Fracture strength for Vita Enamic was higher than the maximum bite force for implant supported restorations in molar region, which came in agreement with Weyhrauch et al.[11]. And it was lower than other resin composite blocks used in this study with statistical significance and it is in agreement with Argyrou and colleagues[24].

In our study, all specimens fractured in the four tested groups, but all titanium abutments remained intact (no catastrophic failure). This manner of fracture could be linked to the type of test (single load to fracture) and to the tested materials elastic properties, as the forces do not directly pass to the abutment or implant[6,25]. Only the Enamic group behave different form the other tested groups (50% code 1 50%, code 2) mode of fracture and this might be related to the difference in its composition as the ceramic network makes the material harder and brittle[23].

However, after optical analysis using a digital stereo microscope, the majority of the crowns had total deboning with the fracture and the cement retained primarily inside the crown, indicating that weakest link was the bond to the abutment[25].

CONCLUSION

Within the limitations of this in vitro study the results showed that different chemical composition and microstructure between the hybrid ceramics and resin-based composite CAD/CAM materials resulted in different resistance to fracture of the implant supported crowns, and all fracture strength recorded were significantly beyond the maximum masticatory forces in the molar region (900 N).

CONFLICT OF INTERESTS

None to declare.

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REFERENCES

1. Beuer F, Stimmelmayr M, Gueth JF, Edelhoff D, Naumann M. In vitro performance of full-contour zirconia single crowns. Dent Mater J. 2012;28(4):449-56.
2. Zhang Y, Kelly JR. Dental ceramics for restoration and metal veneering. Dent Clin. 2017;61(4):797-819.
3. Raigrodski AJ, Hillstead MB, Meng GK, Chung KH. Survival and complications of zirconia-based fixed dental prostheses: a systematic review. J Prosthet Dent. 2012;107(3):170-7.
4. AL-Omiri MK, Sghaireen MG, Alhijawi MM, Alzoubi IA, Lynch CD, Lynch E. Maximum bite force following unilateral implant-supported prosthetic treatment: within-subject comparison to opposite dentate side. J Oral Rehabil. 2014;41(8):624-9.
5. Koyano K, Esaki D. Occlusion on oral implants: current clinical guidelines. J Oral Rehabil. 2015;42(2):153-61.
6. 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.
7. Bijjargi S, Chowdhary R. Stress dissipation in the bone through various crown materials of dental implant restoration: a 2-D finite element analysis. J Investig Clin Dent. 2013;4(3):172-7.
8. Rohr N, Coldea A, Zitzmann NU, Fischer J. Loading capacity of zirconia implant supported hybrid ceramic crowns. Dent Mater J. 2015;31(12):e279-88.
9. Tsitrou EA, Helvatjoglu-Antoniades M, van Noort R. A preliminary evaluation of the structural integrity and fracture mode of minimally prepared resin bonded CAD/CAM crowns. J Dent. 2010;38(1):16-22.

10. Lauvahutanon S, Takahashi H, Shiozawa M, Iwasaki N, Asakawa Y, Oki M, et al. Mechanical properties of composite resin blocks for CAD/CAM. Dent Mater J. 2014;33(5):705-10.

11. Weyhrauch M, Igiel C, Scheller H, Weibrich G, Lehmann KM. Fracture Strength of Monolithic All-Ceramic Crowns on Titanium Implant Abutments. Int J Oral Maxillofac Implants. 2016;31(2).

12. Preis V, Hahnel S, Behr M, Rosentritt M. In vitro performance and fracture resistance of novel CAD/CAM ceramic molar crowns loaded on implants and human teeth. J Adv Prosthodont. 2018;10(4):300-7.

13. Yamaguchi S, Kani R, Kawakami K, Tsuji M, Inoue S, Lee C, et al. Fatigue behavior and crack initiation of CAD/CAM resin composite molar crowns. Dent Mater J. 2018;34(10):1578-84.

14. Zacher J, Bauer R, Strasser T, Rosentritt M. Laboratory performance and fracture resistance of CAD/CAM implant-supported tooth-coloured anterior FDPs. J Dent. 2020;96:103326.

15. Guindy JE, Sherif RE, Aboul-Ezz AA. Evaluation of marginal discrepancy and microleakage of lava ultimate (Resin nano ceramic) versus lithium disilicate (Ips e. max cad) endocrowns. in vitro study. Indian J Sci Res. 2016;7(1):27-34.

16. Tsitrou EA, Northeast SE, van Noort R. Evaluation of the marginal fit of three margin designs of resin composite crowns using CAD/CAM. J Dent. 2007;35(1):68-73.

17. Elsayed A, Farrag G, Chaar MS, Abdelnabi N, Kern M. Influence of Different CAD/CAM Crown Materials on the Fracture of Custom-Made Titanium and Zirconia Implant Abutments After Artificial Aging. Int J Prosthodont. 2019;32(1):91-6.

18. Zimmermann M, Ender A, Egli G, Özcan M, Mehl A. Fracture load of CAD/CAM-fabricated and 3D-printed composite crowns as a function of material thickness. Clin Oral Investig. 2019;23:2777-84.

19. Hafez S, Hafez A, Amr H, Aboudorra HA. Effect of Different Filler Loading on Fracture Resistance of CAD/CAM Resin Composite restoration in Premolar Teeth: An In vitro Study. Egypt Dent J. 2019;65(3):2457-65.

20. Nguyen JF, Migonney V, Ruse ND, Sadoun M. Properties of experimental urethane dimethacrylate-based dental resin composite blocks obtained via thermo-polymerization under high pressure. Dent Mater. 2013;29(5):535-41.

21. Tsujimoto A, Barkmeier WW, Takamizawa T, Latta MA, Miyazaki M. Influence of thermal cycling on flexural properties and simulated wear of computer-aided design/ computer-aided manufacturing resin composites. Oper Dent. 2017;42(1):101-10.

22. Rosentritt M, Krifka S, Strasser T, Preis V. Fracture force of CAD/CAM resin composite crowns after in vitro aging. Clin Oral Investig. 2020;24:2395-401.

23. Hampe R, Theelke B, Lümkemann N, Stawarczyk B. Impact of artificial aging by thermocycling on edge chipping resistance and Martens hardness of different dental CAD-CAM restorative materials. J Prosthet Dent. 2021;125(2):326-33.

24. Argyrou R, Thompson GA, Cho SH, Berzins DW. Edge chipping resistance and flexural strength of polymer infiltrated ceramic network and resin nanoceramic restorative materials. J Prosthet Dent. 2016;116(3):397-403.

25. Lohbauer U, Belli R, Cune MS, Schepke U. Fractography of clinically fractured, implant-supported dental computer-aided design and computer-aided manufacturing crowns. SAGE Open Med Case Rep. 2017;5:2050313X17741015.