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FRACTURE RESISTANCE OF CEMENTED AND INTEGRATED CERAMIC CROWNS SUPPORTED ON ZIRCONIA IMPLANT ABUTMENTS (IN VITRO STUDY)

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ABSTRACT

INTRODUCTION: Even-though the demand for esthetics amplified the popularity of all-ceramic restorations, failures are reported at the interface amid zirconia core and ceramic-veneer.
OBJECTIVES: Comparing fracture resistance and mode of failure of cemented and integrated ceramic crowns supported on zirconia implant abutments.
MATERIALS AND METHODS: Cast having missing upper first premolar; was chosen. Silicone mold was made to duplicate fifteen polyurethane models. Clear surgical guide was fabricated for precise insertion of implant analogue. Models were separated into three groups (n=5). Group I (cemented crowns) Group II (integrated crowns with composite plug) Group III (integrated crowns with ceramic plug). GroupI: Optical impression of zironia abutment was made then crowns were designed, milled, crystallized, and glazed. Then cemented using resin cement. Group II and III crowns were constructed using same technique as Group I but with 2 mm occlusal hole. CAD-on was used to join crowns onto abutments. Group II screw holes were closed using composite resin, while Group III screw holes were scanned, designed, milled using Emax-CAD, then cemented using resin cement. Specimens were fixed to cyclic loading machine for 120,000 cycles, then attached to universal testing machine by cross-head speed (0.5mm/min). Specimens were examined using stereomicroscope and scanning electron microscope.
RESULTS: Highest mean fracture load value was Group I (901.4±54.90)N followed by Group II (790.7±187.4)N then Group III (621.5±97.42)N. Only GroupI and III showed significant difference.
CONCLUSIONS: Cemented crowns showed significant superior fracture resistance than integrated crowns with ceramic plug, and no significant difference with integrated crowns with composite plug.

KEY WORDS: Zirconia abutment, CAD-on, E-max, fracture resistance.
RUNNING TITLE: Fracture of ceramic crowns on zirconia abutments.

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INTRODUCTION

The oral implants performance has encouraged proposal of more beneficial treatment plans suitable to many patients with good prognosis treatment outcomes (1, 2).
Zirconia abutments were recently used as a substitute to other materials as titanuim to combine esthetics with mechanical resistance. Alongside with its strength, its main advantage is the remarkable tissue integration. The successful application of zirconium abutments was reported by various studies proving the firmness of soft tissue and marginal bone related to it. Results signify that the material utilized influence the amount and quality of surrounding periodontium. Also, ceramic abutments diminish bacterial and plaque adhesion and inhibit soft-tissue inflammation (3, 4).
The decision between screw-retained versus cemented-crown is comprehensive, having many points of consideration. Screw- retained crowns are preferred when abutment is shorter than 5 mm. While implant-borne cement-retained prosthesis offer several superiorities, including higher resistance to porcelain fracture and the exclusion of unesthetic access holes which are sealed in screw-retained restorations using diverse restorations. However, abutment height, degree of convergence and surface area and roughness all disturb the durability of a cemented crown on implants as in natural teeth (5-7).
The cementable crown major problem is unreachable excess cement that can cause periodontal damage (5,8). Weber et

al.(9) in their study stated that gingival tissue adjacent to screw-retained crowns was less compromised than around cemented restorations.
During the construction of zirconia-based all-ceramic prosthesis, veneer ceramics used to be made by hand-layering, requiring high technical expertise. In addition, the possibility of prompting porosity during layering justified the veneer fracture (10-12).
Fixed implant prosthodontics, conveyed to digital computer assisted design and computer-aided manufacturing (CAD/CAM) technology providing relentless quality and a cost benefit ratio (13).
A new CAD/CAM veneering technique (CAD-on) is a CEREC 3D to design and mill zirconia coping then mill the veneer. Which were joined by ceramic fusing agent, applied to the interior wall of the veneer and top of the coping. Finally, the crystallization firing of the assembly (10).
The boundary of zirconia core and ceramic veneer arise most failures in all-ceramic zirconia based prosthetics regardless of the structural stability of zirconia. To lessen chipping frequencies; as substructures with reduced anatomically design, adequate width of the veneering, cooling during the veneering procedure, and equivalent coefficients of thermal expansion ceramics used (14-19).
A clinical report suggested a pressed porcelain insert for closure of the screw access of prosthesis for better occlusion, and esthetics similar to cement-retained crown, but inhibiting the concerns of excess cement (20).
This study was attempted to compare fracture resistance and fracture mode of cemented and integrated glass ceramic crowns supported on zirconia implant abutments. The null hypothesis tested is that joining protocol between ceramic crowns and zirconia implant abutments didn't influence the resistance fracture of crowns.

MATERIALS AND METHODS

The study was conducted after receiving the approval of the ethical committee at Faculty of Dentistry, Alexandria University, Egypt.
A Cast having missing upper right first premolar; was chosen for this work. Silicone mold was fabricated and fifteen polyurethane models were duplicated. A clear surgical guide was fabricated for precise drilling for insertion of implant analogue. The implant analogue was secured into its right position and implant abutment attached to it.
The obtained fifteen polyurethane models with implant analogue in place were randomly divided to three main groups according to either the crowns cemented or integrated with composite or ceramic insert. Each group consists of five models.
Group I : Cemented ceramic crowns supported on zirconia abutments
Group II : Integrated ceramic crowns with composite resin closing the screw access channel supported on zirconia abutments
Group III : Integrated ceramic crowns with ceramic insert closing the screw access channel supported on zirconia abutments
Crowns design and fabrication for Group I
All zirconia abutments were sand-blasted. Then zirconia abutments on the epoxy resin models, adjacent and opposite teeth surface were covered with a uniform thin layer of optical reflective powder (Titanium dioxide; Vita Zahnfabrik) to decrease light reflection.
Optical impression was taken for them using Sirona inEOS X5 extra-oral scanner. Scanned data were transferred to the Sirona Inlab software following the designing steps for a full anatomy upper premolar crown. Emax CAD ceramic blocks were milled utilizing Sirona MC X5 milling machine. All crowns were then subjected to crystallization, and glazing.
Cementation of the crowns each crown was positioned on its respective implant abutment to check for fitting. Then internal surface of crowns all were etched with 5% hydrofluoric acid (Ceramic Etching Gel) for 20s.Thoroughly rinsed utilizing water spray and dried by oil-free air (21). Then, all the ceramic crowns were primed with a thin coat of a universal primer Monobond Plus (IvoclarVivadent) for 60 seconds using micro-brush.
All crowns were cemented using Multilink automix dual cure resin cement. Specimens were then light cured under static load of 5 Kg. and put in place for 3 minutes till complete setting. Excess cement was removed.
Crowns design and fabrication for Group II
Crowns were fabricated utilizing the same technique as in Group I but crowns were designed having a 2 mm hole on the occlusal surface corresponding to that of the abutment. Designed restorations were milled from e-max CAD blocks using the Sirona MC X5 milling machine. No crystallization or glazing to any crown in this phase.
IPS e-max CAD-on crystal/connect was used to join the crowns onto their corresponding zirconia abutments. IPS e-max CAD-on capsule was pressed onto the vibrating plate of Ivomix (vibrating device) for approximately 10-15 seconds and slightly agitated to allow flowability of the material (22).
After application of the CAD-on into the e-max crowns, zirconia abutments were positioned into their corresponding e-max crowns and again the assembly was slightly pressed against the vibrating plate then fired at a temperature of 840℃; for both crystallization of e.max crowns and fusion of CAD-on to both e.max material and zirconia using specific parameters.
The screw holes for this group crowns were etched using 5% hydrofluoric acid etch for 20s. Thoroughly showered utilizing water spray and oil-free air dried. Then, primed with a micro-brush using a universal primer Monobond Plus for 60 seconds, then dispersed using air stream.
After complete drying Scotchbond Universal Adhesive was applied with a micro-brush, then they were plugged using composite resin (3M ESPE).
Crowns design and fabrication for Group III
Same procedures as in group II were done for fabricating and integrating the crowns on their corresponding zirconia abutments.
Screw holes for this group were scanned and ceramic inlay plug (Insert) was designed and milled using CAD/CAM out of E-max CAD blocks, then etched, primed and cemented using resin cement.

For aging all specimens were stabilized to cyclic loading machine with a mean cyclic loading of 50 N for 120,000 cycles.
Compressive axial load by cross-head speed (0.5 mm/min) into the universal testing machine was done to all samples. Fractured specimens were analyzed using stereomicroscope and SEM to identify the failure mode.
To categorize the failure mode of the specimens, they were examined using:

- III is crown fracture from side to side along the midline Stereomicroscope: All broken de-bonded surfaces were inspected at 2.5x magnification to identify the failure mode.
- Scanning electron microscopy examination (SEM): A sample of each group was selected for analysis to determine the micro-fractography. Specimens were coated using gold and inspected at accelerated 15Kv and magnification 35x and 1000x.

Possible failure modes were classified according to pattern of fracture as described by Burke (23)

- Mode I a slight breakage or crack in the crown
- Mode II is inferior to half the crown lost
- Mode with half of the crown displaced or lost
- Mode IV is further than half of the crown lost
- And mode V is drastic fracture of the tooth and/or crown.

Also failure modes were classified according to pattern of de-bonding as classified by Sherrer et al. (24)

- Adhesive failure of tooth and ceramic into the cement junction (less than 10% the bonding).
- Cohesive among tooth and/or resin cement (more than 40% of the bonding).
- Mixed failure [Mainly adhesive of ceramic and tooth surface and/or resin cement or mostly cohesive within tooth and resin cement (less than 40% of bonding)].

Statistical analysis

Data fed to the computer and investigated using IBM SPSS software package version 20.0. (Armonk, NY: IBM Corp) Qualitative data were described by number and percent. The Kolmogorov-Smirnov test was utilized to verify the normality of distribution. Quantitative data were termed using range (minimum and maximum), mean, standard deviation and median. Significance of the acquired results was adjudged at the 5% level.
The used tests were F-test (ANOVA) to compare the quantitative data between the tested groups, and Post Hoc test (Tukey) for pairwise comparisons.

RESULT

The highest mean fracture load for Group I was (901.4 ± 54.90) N followed by Group II value (790.7 ± 187.4) N and Group III showed the lowest mean value of (621.5 ± 97.42) N. The mean values of fracture loads in newton for all groups and the descriptive statistical analysis are shown in table (1).
ANOVA statistical analysis test revealed significant difference concerning the groups ($p \le 0.05$). Post Hoc test (Tukey) showed that there was:

- No significant difference on comparing between Group I and II (P1*= 0.377).
- No significant difference resulted between Group II and III (P3*= 0.127).
- While comparing Group I and III significant difference between them was found. (P2*= 0.011) (Table 1 and Figure 1)

Evaluation of the modes of failure according to pattern of fracture as in 1990 by Burke (23) (Table 2 and Figure 2, 3, and 4)

- Group I (cemented crowns) all specimens showed failure mode III (a crown fracture through the midline with buccal half of crown lost),
- Group II (integrated crowns with composite plug) all specimens showed failure mode III (fracture through the midline and buccal half of the crown lost),
- Group III (integrated crowns with ceramic plug) three specimens showed failure mode III (fracture through the midline with buccal half of the crown lost), while two specimens presented a different mode of fracture which is mode IV (more than half the crown lost).

Evaluation of the patterns of de-bonding as in 2010 by Sherrer et al. (24) (Table 3 and Figure 2, 3, and 4)
In Group I (cemented crowns) four samples showed adhesive pattern of failure while only one sample showed mixed pattern predominantly adhesive.
While in Group II (integrated crowns with composite plug) two samples showed a cohesive pattern of failure while three samples showed mixed pattern of failure where two samples were mainly cohesive and the last was predominantly adhesive.
While in Group III (integrated crowns with ceramic plug) two samples showed a cohesive pattern of failure while three samples showed mixed pattern of failure where two samples were mostly adhesive and the other was predominantly cohesive.

Table (1): Comparison between the three studied groups according to fracture resistance (N) test
F: F for ANOVA test, Pairwise comparison between each 2 groups was done using Post Hoc Test (Tukey)
p: p value for comparing between the studied groups
p1: p value for comparing between Group I and Group II
p2: p value for comparing between Group I and Group III
p3: p value for comparing between Group II and Group III

Fracture resistance test	Group I (n=5)	Group II (n=5)	Group III (n=5)	F	P
Min. – Max.	832.5 – 978.8	583.1 – 1081.5	481.4 – 723.6	6.256*	0.014*
Mean ± SD.	901.4 ± 54.90	790.7 ± 187.4	621.5 ± 97.42		
Median	905.6	769.1	605.7		
Sig. bet. Grps	p1=0.377, p2=0.011*, p3=0.127				

*: Statistically significant at $p \le 0.05$

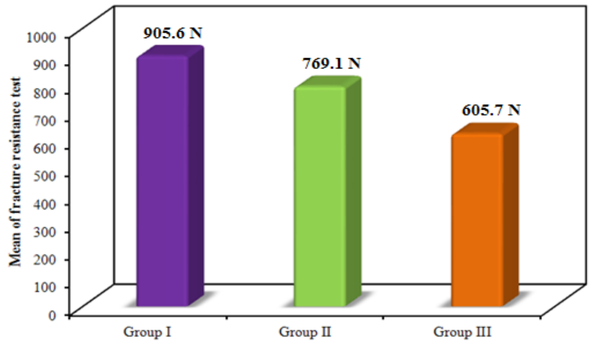

Figure 1: Comparison between the three studied groups according to fracture resistance (N) test

Table (2): Percentage of fracture pattern of failure of the three studied groups according to Burke (1999) (26)

Modes of failure	Samples			Percentage%
	Group I	Group II	Group III	
Mode I	-	-	-	
Mode II	-	-	-	
Mode III	5	5	3	86.6 %
Mode IV	-	-	2	13.3 %
Mode V	-	-	-	

Table (3): Evaluation of the patterns of debonding of the three studied groups according to Scherrer et al. (2010) (27)

Modes of failure		Sample			Total
		Group I	Group II	Group III	
Cohesive		-	2	2	4
Adhesive		4	-	-	4
Mixed	Predominantly Adhesive	1	1	2	4
	Predominantly Cohesive	-	2	1	3
No of specimens		5	5	5	15

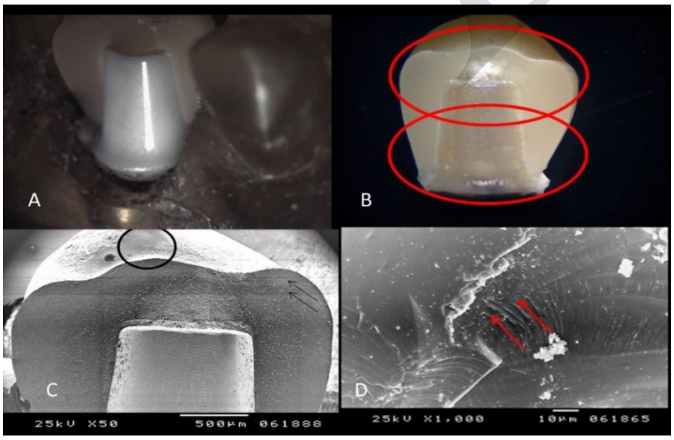

Figure 2: Stereomicroscope and SEM pictures showing mode of failure of Group I

(A&B) Stereomicroscope images with magnification 2.5x showing the buccal and lingual parts. Stereomicroscope images show type III mode of failure & adhesive failure type of specimen. The parts encircled in red are shown in SEM.
(C) SEM magnification of the occlusal half of figure (1.B) showing presence of adhesive failure where all cement adhere to the e-max crown surface.
Black circle showing an occlusal indentation indicating Hertzian ring/cone cracking, while black arrows show hackles.
(D) Fracture origin and direction of crack propagation (DCP), hackles, compression curves (marked by red arrows) & white lines goes along arrest line.

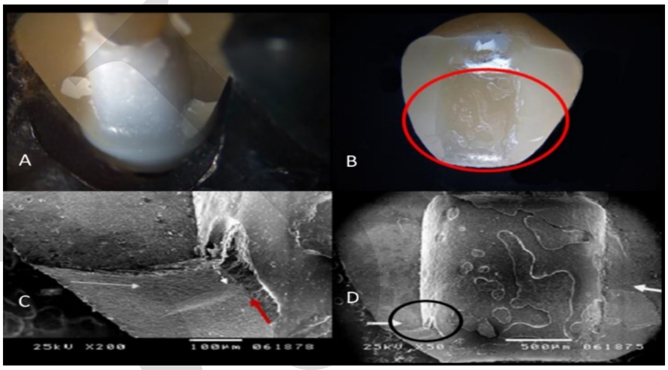

Figure 3: Stereomicroscope and SEM pictures showing mode of failure of Group II
(A&B) Stereomicroscope images with 2.5x magnification showing buccal and lingual parts after fracture. Stereomicroscope images show type III mode of failure & cohesive mode of fracture within crystal/connect fusion glass. Red circle magnified in SEM in fig (3.C&D)
(C&D) SEM showing presence of cohesive E-max fracture. Black circle magnified in adjacent picture. White arrows on figure showed crack propagation starting cervically. White Arrow showed hackles, direction of crack propagation (DCP) and dotted arrow showed multiple twisted hackles and the red arrow showed arrest line.

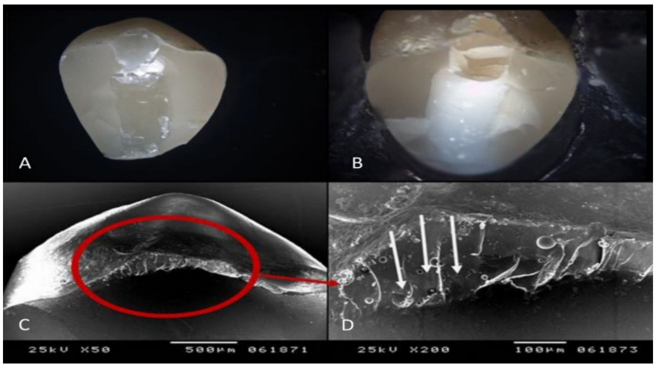

Figure 4: Stereomicroscope and SEM pictures showing mode of failure of Group III
(A&B) Stereomicroscope images with 2.5x magnification showing buccal and lingual parts after fracture. Images show type III mode of failure & cohesive mode of fracture within crystal/connect fusion glass.
(C&D) SEM showing presence of cohesive E-max fracture. White arrows showed wake hackles pattern of fracture and direction of crack propagation (DCP).

DISCUSSION

The fracture resistance and failure mode of cemented and two types of integrated CAD-on lithium disilicate crowns supported on zirconia abutments, one with composite resin closing the screw access and the other with ceramic insert.
A 3D printed out clear drilling surgical guide was fabricated to ensure implant analogue placement within its place into the polyurethane models (25).
Zirconia abutments were used due to their biocompatibility, advanced esthetics, high flexural strength (900-1200 MPa), fracture toughness (6 MPa·m1/2) and compressive strength (2000MPa) (26).
CAD/CAM was used to design and mill the e-max crowns for better control, accuracy, esthetics and to eliminate human factor. The CAD/CAM Software ensured centralization of the screw access hole of 2 mmD in the integrated crowns over the screw access of the scanned readymade zirconia abutments (27).
Lithium disilicate ceramic was selected for this study's crowns of first premolar for its color and translucency similar to natural teeth and its superior mechanical properties (28).
Dual cure resin cement (chemical & light cure) was used as it can develop a bond to both ceramic materials used, either etched glass ceramics or sandblasted zirconia.
CAD-on technique was developed reducing the difficulties faced with the layering and pressed approaches (29).
According to the manufacturer, CAD-on crystal/connect creates a homogenous connection between the outside of the framework and the inside of the veneer in a process named glass fusion (29).
The specimens were mounted in a cyclic loading machine calibrated to deliver 120,000 cycles with 50N occlusal load which resembles the function of 6 months in patient mouth (30) Also to simulate conditions similar to the clinical situation, on the loading side of the machine, lower premolars in acrylic blocks was positioned in a right occlusal relation to tested crowns.
After aging test crowns showed no fracture or chipping. No loosening of any abutment or abutment's screw was detected either. That might be due to lithium disilicate crowns on zirconia abutments showing good mechanical properties and durability (31).
The result of the current study (Group I) (cemented crowns) showed highest fracture resistance, also significant compared to Group II and Group III (integrated crowns).
The reduced fracture resistance of the integrated crowns (Groups II and III) might be attributed to the existence of screw access which weakens their structure compared to the undisturbed monolithic construction of cemented crowns (Group I). It was In agreement with a study in 2010 by Al-Omari et al., (32) who believe that the screw access at the occlusal surface affects the resistance of fracture of prosthetic crowns, which frequently leads to biomechanical complications and the fracture of the veneering porcelain that affect the durability of the restoration.
However, in a 2015 study by Derafshi et al., (33) they found in disagreement with the previous mentioned papers no significant difference between the cemented crowns group and the screw retained groups concluding that the presence of screw access channel did not affect fracture resistance.
All crowns from Group I and Group II and three out of five crowns in Group III showed cohesive failures in the ceramic into two fragments mesiodistally separating the crown into buccal and palatal parts, though the abutment persisted intact. This pattern of failure is referred to the forces applied on the occlusal-surface inducing external dislodgment of the buccal and palatal cusps, with a load concentration on the abutment causing a fracture line in mesio-distal direction as found by Stona et al. (34).
Also in agreement with a study in 2015 by Nossair et al., (27) using fractographic analysis to analyze the variance between "CAD-on" groups, glass/fused groups, and a hand layering control group they concluded that cemented "CAD-on" veneers established higher resistance to fracture than glass fused and manual layered veneers.
For cemented crowns, the cement acts as a cushion to the brittle veneer, absorbing stresses, and increasing fracture-resistance. Moreover, the heating cycle is evitable in cementation method compared to the CAD-on fusing-glass heated to melt between the veneer and the zirconia, producing stresses as the crystal/connect interface while cooling down, and shrinking in a tight space (27, 35).
All zirconia abutments persisted intact while all e-max crowns were fractured. This finding could be related to the great content of crystals of zirconia material that resulted in better properties while the lithium disilicate ceramics have glassy matrix reinforced with lithium disilicate crystals. Also it could be owing to the transformation toughness phenomena of zirconium material giving it a higher fracture resistance value (34).
Noticing the least resistance to fracture value of Group III could be due to the brittleness and lack of resiliency of the ceramic plug used for screw access channel closure on contrary to the resiliency of composite used for screw access channel closure of Group II.
Supporting the current study, Amesti-Garaizabal et al., (36), stated that composite materials revealed a greater ability to absorb compressive forces in comparison with porcelain materials, where composite decreased the impact forces by 57%.
Four out of ten integrated crowns showed cohesive fracture originating within the veneering ceramic. Similar results were reported evaluating the same materials. Possibly, referred to internal stresses or pressure distribution pattern within the restoration (27).
Thus, the null hypothesizes was rejected in this study concluding that fracture resistance of ceramic crowns was affected by type of retention either by cementation or integration of ceramic crowns with zirconia abutments.

CONCLUSIONS

Within the confines of this study, it could be concluded that:

1. Cemented E-max crowns on zirconia abutments using resin cement show higher fracture resistance than integrated Cad-on crowns.

2. Composite closure of screw access improved the fracture resistance of integrated crowns over CAD/CAM ceramic plug.
3. Cyclic loading had no effect on cemented or integrated crowns.

CONFLICT OF INTREST
The authors declare that they have no conflict of interest.

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