



Evaluation of Shear Bond Strength and Biaxial Flexural Strength of Zirconia Cores Veneered Using CAD-on and Press-on Techniques

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تقييم مقاومة رابطة القص وقوة الانحناء ثنائي المحور لقلوب الزركونيا المغطاة باستخدام تقنيتي
Press-on و CAD-on

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Abstract:

Objectives: This in vitro study compared the shear bond strength and biaxial flexural strength of CAD/CAM-fabricated zirconia cores veneered using CAD-on and Press-on techniques and evaluated their modes of failure. Materials and Methods: Twenty zirconia core discs were fabricated from IPS e.max Zir CAD using CAD/CAM technology. Ten specimens were prepared for shear bond strength testing and ten for biaxial flexural strength testing, with five specimens allocated to each veneering technique per test. The CAD-on group was veneered using IPS e.max CAD, whereas the Press-on group was veneered using IPS e.max ZirPress. All specimens underwent thermocycling before testing. Failure modes were evaluated using scanning electron microscopy, and data were analyzed using SPSS software with the level of statistical significance set at $p \leq 0.05$. Results: The t-test analysis of the shear strength test showed a statistically significant difference ($p < 0.05$) for the CAD-on group. There were no statistically significant differences ($p > 0.05$) for the biaxial flexural strength test between the two groups. The CAD-on group showed adhesive/cohesive failure, while the Press-on group showed cohesive failure within the veneering ceramic. Conclusion: Within the limitations of this in vitro study, the veneering technique affected shear bond strength. The CAD-on technique showed significantly higher shear bond strength than the Press-on technique. Biaxial flexural strength did not differ significantly between the techniques.

Keywords: Zirconia, CAD-on technique, Press-on technique, Shear bond strength, Biaxial flexural strength, Veneering ceramics, Failure mode.

المخلص

الأهداف: هدفت هذه الدراسة المخبرية إلى مقارنة مقاومة رابطة القص وقوة الانحناء ثنائي المحور لقلوب الزركونيا المصنعة بتقنية CAD/CAM والمغطاة باستخدام تقنيتي CAD-on و Press-on، وتقييم أنماط الفشل لديهما. المواد وطرائق العمل: تم تصنيع عشرين قرصاً لقلب الزركونيا من مادة IPS e.max Zir CAD باستخدام تقنية CAD/CAM. جُهزت عشر عينات لاختبار مقاومة رابطة القص وعشر عينات لاختبار قوة الانحناء ثنائي المحور، مع تخصيص خمس عينات لكل تقنية تغطية في كل اختبار. غُطيت مجموعة CAD-on باستخدام مادة IPS e.max CAD، بينما غُطيت مجموعة Press-on باستخدام مادة IPS e.max ZirPress. خضعت جميع العينات لدورات الحرارة قبل الاختبار. تقيمت أنماط الفشل باستخدام المجهر الإلكتروني الماسح، وحُللت البيانات باستخدام برنامج SPSS مع تحديد مستوى الدلالة الإحصائية عند $p \leq 0.05$.

النتائج: أظهر تحليل اختبار t لمقاومة القص وجود فرق ذو دلالة إحصائية ($p < 0.05$) لصالح مجموعة CAD-on. ولم تكن هناك فروق ذات دلالة إحصائية ($p > 0.05$) لاختبار قوة الانحناء ثنائي المحور بين المجموعتين. أظهرت مجموعة CAD-on فشلاً لاصقاً/متلاحماً، بينما أظهرت مجموعة Press-on فشلاً متلاحماً داخل سيراميك التغطية. الاستنتاج: في حدود هذه الدراسة المخبرية، أثرت تقنية التغطية على مقاومة رابطة القص. أظهرت تقنية CAD-on مقاومة رابطة قص أعلى بكثير من تقنية Press-on. ولم تختلف قوة الانحناء ثنائي المحور بشكل ملحوظ بين التقنيتين.

الكلمات المفتاحية: الزركونيا، تقنية CAD-on، تقنية Press-on، مقاومة رابطة القص، قوة الانحناء ثنائي المحور، سيراميك التغطية، نمط الفشل.

Introduction

The demand for all-ceramic dental prostheses increased significantly in the twentieth and twenty-first centuries, and the advanced processing technology of these materials makes them of great interest to patients, dentists, and technicians.

The aesthetic, strength and biocompatibility of Zirconia base material improved its use for both crowns and fixed partial dentures. Among different types of ZrO₂ ceramics, the most frequently used material is Yttria-stabilized Tetragonal Zirconia Polycrystal (Y-TZP), which was introduced in the early 1990s. Compared to other core ceramics, Y-TZP ceramic demonstrates better mechanical properties and superior resistance to fracture. Yttrium oxide (Y₂O₃, 3% mol) is added to pure zirconia to control the volume expansion and to stabilize it in the tetragonal phase at room temperature⁽¹⁾. Zirconium dioxide- based ceramics (ZrO₂) have been applied to clinical use through the computer- aided design/computer-aided manufacturing technologies (CAD/CAM)⁽²⁾. Either the layering technique or the press-over technique can be used for veneering the zirconia cores. The layering technique allows superior aesthetic results compared with the Press-on technique, which has the advantages of being faster and less costly⁽³⁾.

Beuer et al., (2009)⁽⁴⁾ introduced a new procedure for veneering all-ceramic crown restorations using a CAD/CAM-fabricated high-strength zirconia coping and a corresponding CAD/CAM-fabricated lithium-disilicate glass-ceramic veneering material. It can be assumed that this procedure of sintering core and veneering leads to an increase in mechanical strength compared to traditional techniques, enabling a lower clinical chipping rate of the veneering material due to the use of CAD/CAM-generated high-strength veneering ceramics.

This in-vitro study aimed to compare the shear bond strength and biaxial flexural strength of CAD/CAM-fabricated zirconia cores veneered using CAD-on and Press-on techniques and to evaluate the associated failure modes.

Materials and methods

Specimen Preparation for Shear Bond Strength Test:

Core fabrication: Ten Zirconia core discs were constructed, 5 mm in diameter and 4 mm in thickness from IPS e-max ZirCAD blocks, the discs were randomly allocated to two groups (n=5): CAD-on and Press-on

Veneer fabrication:

CAD-on technique

Five veneer discs 3 mm in diameter and 3 mm in thickness, were milled from IPS e.max CAD blocks. The sintered zirconia discs were fused to the milled IPS e-max CAD discs by low fusing ceramic (IPS e-max CAD crystal/connect fusion glass ceramic), which came in a form of capsule that was put under vigorous vibrations through Ivomix device that converted it into an applicable form, the discs were then entered fusing/crystallization firing cycle in ceramic furnace (program at p 300), using the following parameters; Table 1.

Table 1. Fusion/crystallization firing parameters for the CAD-on technique.

B	S	t1	T1	H1	t2	T2	H2	V1/ v12	V2/ v22	L
403	2:00	30	820	2:00	30	840	7:00	550/820	820/840	600

Where:

B: starting temperature (°C), S: closing time (min), t1: heating rate, phase1(°C/min), T1: firing temperature, phase 1(°C), H1: holding time, phase 1 (min), t 2: heating rate, phase 2 (°C/min), T2: firing temperature, phase 2 (°C), H2: holding time, phase 2 (min), V1: vacuum on, V2: vacuum off, L: long-term cooling (°C).

Press-on technique

Zirconia discs were prepared via sandblasting with 50 µm Aluminum oxide (Al₂O₃) and application of IPS e-max Ceram ZirLiner to achieve a sound bond between zirconia discs and IPS e-max ZirPress veneering material.

Waxing up and investing were done by using a double-diameter copper mould, 5 mm in diameter and 4 mm in thickness, 3 mm in diameter and 3 mm in thickness, zirconia discs were placed in the larger diameter space, a sprue wax (3×3 mm) was fixed on it and completed on an investment ring (100 g), invested, then entered the burn-out furnace according to the manufacturer's instructions.

Pressing is done using a cold IPS Alox Plunger and IPS e-max ZirPress ingots in the desired shade, which were placed into the hot investing ring, with shade imprint facing upward. The investing ring was then put in the centre of the hot press-furnace (EP 3000), and pressing was done according to the parameters described in Table 2. After the press program was completed, the ring was allowed to cool down to room temperature.

Table (2): Press program parameter (°C)

B	t	T	H	E
700	60	900	15:00	300

B: Starting temperature [°C], t: Heating rate [°C /min], T: Firing temperature [°C], H: Holding time [min], E: end of program (um/min)

After cooling, the length of the Alox plunger was marked on the cooled investment ring. These predetermined breaking points enabled the reliable separation of the investment material and the discs. A separating disk was used to separate the investment ring. Polishing beads were used to clear the pressed discs.

The reaction layer on the surface of the discs was removed by immersing them in IPS e-max Press Invex Liquid for 30 minutes according to the manufacturer's instructions. Then they were rinsed with running water and dried, and final finishing was done.

Glaze was applied and fired according to the manufacturer's instructions.

Specimen's Preparation for Biaxial Flexural Strength Test:

(A) Core fabrication

Ten zirconia core discs, 12 mm in diameter and 0.7 mm in thickness, were fabricated from IPS e.max ZirCAD blocks and allocated to two groups (n=5): CAD-on and Press-on.)⁽⁵⁾

(B) Veneer fabrication:

CAD-on technique: same as above, but the size of the veneer disc is 12×0.8 mm.

Press-on technique: using the same technique mentioned above, but the size of the veneer disc is 12 mm in diameter and 0.8 mm in thickness

The test specimens were subjected to a thermocycling machine for 600 cycles (corresponding to one year), between 55⁰ C and 5⁰ C with a dwell time (time taken by the specimens in each bath) of 2 minutes, and a transfer time of 10 seconds⁽⁶⁾.

Testing of the specimens:

A. Shear Bond Strength Test:

Each specimen was fixed in an acrylic mould and secured to the lower plate of the universal testing machine** by a specially designed jig. The knife-edge blade of the universal testing machine was held against the zirconia/ceramic veneer interface, and a shear force was applied to each specimen at a crosshead speed of 1 mm/min until failure occurred. The load at which the failure occurred was recorded in Newton⁽⁷⁾.

The Shear bond strength was calculated according to the following equation:

$$\text{Shear stress (MPa)} = \text{Load (N)} / (\Pi \times r^2) \text{ N/mm}^2$$

Where, $\Pi = 3.14$

r = radius of the specimen

N = load in Newton

Selected fractured specimens were examined under scanning electron microscopy to evaluate the mode of failure.

B. Biaxial Flexural Strength Test:

Each disc was fixed to the lower plate of the universal testing machine by a specially designed jig, in which each disc was placed on a circular 10-mm-diameter knife-edge support, and the load was applied centrally at a rate of 1 mm/minute with a spherical indenter of 5 mm⁽⁸⁾.

During testing, all the specimens were placed with the glazed veneer surface facing upward toward the indenter and a thin sheet of rubber was placed between the disc and the knife-edge support to accommodate slight irregularities in the disc⁽⁸⁾. The biaxial flexural strength was calculated according to the following equation⁽⁹⁾

$$T = \frac{W}{4\pi} \left[(1 + \nu) \log \frac{A}{R} + 1 \right]$$

$$R = \sqrt{1.6B^2 + d^2} - 0.675d$$

Where:

T is the maximum tensile stress, W is the measured load at fracture, V is Poisson's ratio for the material (A value of 0.25 was substituted for the material), R is the equivalent radius of loading, A is the radius of the knife-edge support, B is the radius of the tip of the piston, and d is the thickness of the specimens.

Statistical Analysis:

All data were collected and analyzed statistically by using the SPSS program software (Statistical Package for Social Science- version 20.0), with a significance level of 5%, where $p \leq 0.05$.

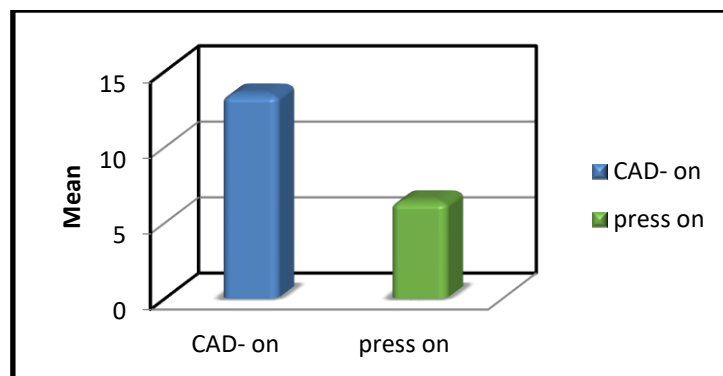
Results

Shear bond strength: The CAD-on group demonstrated a significantly higher mean shear bond strength than the Press-on group (13.49±3.62 MPa versus 6.44±0.41 MPa, respectively). The difference between groups was statistically significant ($t=4.325$, $p=0.003$), as shown in Table 3 and Graph 1.

Table 3. Shear bond strength results

Group	Minimum (MPa)	Maximum (MPa)	Mean ± SD (MPa)	t value	p value
CAD-on	10.65	18.48	13.49±3.62	4.325	0.003
Press-on	5.89	7.01	6.44±0.41		

t and p-values were calculated using the Student t-test



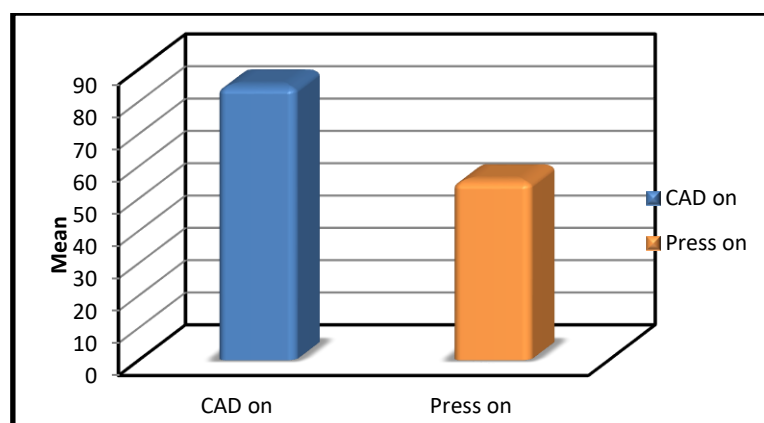
Graph 1: Mean value of shear test of the two studied groups.

Biaxial flexural strength: The CAD-on group showed a higher mean biaxial flexural strength than the Press-on group (84.93±38.51 MPa versus 55.57±37.45 MPa, respectively). However, the difference was not statistically significant ($t=1.22$, $p=0.26$), as shown in Table 4 and Graph 2.

Table 4. Biaxial flexural strength results.

Group	Minimum (MPa)	Maximum (MPa)	Mean ± SD (MPa)	t value	p value
CAD-on	54.60	150.14	84.93±38.51	1.22	0.26
Press-on	26.96	121.29	55.57±37.45		

t and p-values were calculated using the Student t-test



Graph (2): Mean value of biaxial flexural strength of the two test groups.

Failure Mode Analysis

All CAD-on specimens (n=5;100%) exhibited mixed adhesive/cohesive failure. All Press-on specimens (n=5;100%) exhibited cohesive failure within the veneering ceramic.

Discussion

Ereifej et al, (2011)⁽¹⁰⁾ stated that the bond strength and the quality between the veneer and the ceramic core are the key factors in the success of bilayered restorations.

In the current study, yttrium oxide partially stabilized zirconia (Y-TZP) was selected as a core material. It is industrially manufactured into blanks and milled to the desired dimensions using CAD/CAM technology. Cores made in this way are stable, have a high crystalline content and flexural strength of 900–1200MPa⁽¹¹⁾.

The combination of a CAD/CAM-fabricated framework with CAD/CAM-fabricated veneering would be of major interest, especially if considerably stronger veneering ceramics can be applied⁽⁴⁾. Lithium-disilicate reinforced glass-ceramic (IPS e-max CAD) is one of the veneering ceramics that are used for a zirconia framework. Since it is industrially produced into ceramic blanks, it shows fewer faults compared to manually produced veneers⁽⁴⁾. Thus, the fatigue behavior and the fracture strength are supposed to be superior in these materials compared to hand-layered ceramics⁽¹²⁾. Additionally, the material properties of IPS e-max CAD ceramics (flexural strength: 360 MPa) are superior compared to those of hand-layered feldspathic ceramics (flexural strength about 100 MPa)⁽¹³⁾. This ceramic is suitable for the sinter bond technique with zirconia frameworks due to the appropriate match of the coefficients of thermal expansion (CTE of IPS e-max ZirCAD= $10.75 \times 10^{-6} \text{ K}^{-1}$, CTE of IPS e-max CAD= $10.25 \times 10^{-6} \text{ K}^{-1}$)⁽⁴⁾. These features were the basis for selecting this material for use in the present study.

It was reported that zirconia veneer bond strength is affected by veneering techniques⁽¹⁴⁾. An advanced veneering category is the CAD-on technique, which was used in this study. It involves both the framework and the veneer being CAD/CAM manufactured, resulting in almost faultless components, as the ceramic blanks are industrially produced⁽¹⁵⁾. After the manufacturing of the framework and the veneer, the components are joined together using fusion glass ceramics in a specially programmed furnace⁽¹⁶⁾. This technique combines both strength and esthetic (translucency) of restoration. However, little information is available about the behavior of these completely CAD/CAM-manufactured restorations⁽¹⁷⁾.

Heat-pressing materials have become available to produce a veneering layer for all ceramic restorations⁽¹⁸⁾ and have shown improved mechanical fatigue properties and clinical performance of all ceramic restoration⁽¹¹⁾. IPS e-max ZirPress is a fluorapatite glass-ceramic ingot; it has an appropriate coefficient of thermal expansion with respect to zirconia. (IPS e-max ZirPress= $9.75 \pm 0.25 \times 10^{-6} \text{ K}^{-1}$), (IPS e-max ZirCAD ($10.75 \times 10^{-6} \text{ K}^{-1}$)⁽⁴⁾. With a flexural strength of ($110 \pm 10 \text{ MPa}$). These reasons might explain the use of this material in this study.

Press-on technique is a veneering category used in this study; it combines both performance improvement and better bonding to the zirconia framework as compared with conventional layering⁽¹⁴⁾. Press-on technique depends on the lost-wax technique, where the required shape and form of the veneer ceramic is obtained under controlled temperature, pressure and vacuum parameters, which reduces the possibility of thermal fatigue and incorporation of structural defects, although wax design remains operator-dependent and a factor of human error exists⁽¹⁹⁾.

In the current study, standardization of the specimens of each test group was done by producing them from the same standard moulds, with the same dimensions.

In this study, a thermocycling regime was conducted to simulate intra-oral temperature changes. According to Krejci et al (1993)⁽⁹⁾, 600 cycles corresponded to one year of clinical performance.

In the present study, the shear bond strength (SBS) test was used to determine the core-veneer bond strength. In the (SBS) test, the stresses determined for each specimen are the best normal approximation of the actual stresses applied on fixed partial dentures at the location of failure⁽²⁰⁾. Also, the failure process under a knife-edge is similar to the stress concentration effect on the occlusal contact⁽²¹⁾. On the other hand, it resulted in more standardized data, because the applied forces are perpendicular to the bonding area, and the small cross-sectional area of the bonded surface eliminates incorporation of structural flaws, which significantly affect test readings.

In this study, the biaxial flexural strength test (BFS) was also used; it was added to the ISO standard for dental ceramics (ISO 6872-1994)⁽²²⁾. The test provides an equal biaxial stress distribution, and a maximum tensile stress occurs at the central loading area rather than at the edges⁽²³⁾. It has been introduced to measure the tensile strength of brittle materials such as ceramics, because the disc-shaped specimens are closer in size and volume to dental restorations than bars used for other tests. Also, the biaxial strength test is well known to induce a very complex state in the test specimens and thereby simulate the intra-oral situation encountered by the restoration⁽²⁴⁾. A wide variety of loading arrangements have been developed for biaxial flexure tests, one of which is the ball-on-ring test, which was selected in this study⁽²⁵⁾.

Regarding shear bond strength, the results revealed a significant difference between the CAD-on and Press-on techniques, with the CAD-on technique showing a significantly higher shear bond strength than the Press-on technique. This might be attributed to the fabrication methods of these two ceramic systems.

In CAD-on group, digitalization was used in the fabrication of the specimens, which might have influenced their bond strength. Digitalization results in an accurate sample size and dimension, which affects precise fitness and adaptation between the core and veneer. This yields a very thin, uniform layer of fusing ceramic. This fusing ceramic had high fusion capability and flow properties, which are enhanced by vigorous vibration (230 Hz). The excellent wetting ability of zirconia would enable some degree of penetration of the fusing ceramic along the Y-TZP boundaries.

Vigorous vibration also helps to eliminate structural defects such as air bubbles, voids and micro-gaps, thereby eliminating stress concentration sites. The fusing ceramic had a matched coefficient of thermal expansion to both IPS e-max- ZirCAD core and the IPS e-max CAD veneer, and as it entered with the veneer, the same cycle with high temperature, this resulted in completely homogeneous fusion and bonding from both sites, resulting in a compressive bond between the core and the veneer. Also, the fusing ceramic and IPS e-max CAD veneer was allowed to cool at the same cooling rate, and this might decrease the cooling stress. All these reasons might explain the high bond strength obtained in the CAD-on group. Press-on techniques showed lower bond strength than CAD-on technique, demonstrating that adhesion of IPS e-max ZirPress to zirconia was low. This might be attributed to the difference in the structure and fabrication techniques used for both core and veneer, as the zirconia core was CAD/CAM fabricated, while the veneer was heat pressed.

This result is consistent with Choi et al., (2011)⁽²⁶⁾ who found that non-leucite-containing glass ceramic had less adhesion to zirconia than leucite-containing glass ceramic, and IPS e-max ZirPress is a non-leucite-containing glass ceramic.

Regarding the mode of failure in the current study, the results revealed that the specimens displayed adhesive/cohesive failure in CAD-on group, while they showed cohesive failure limited within the veneer material in Press-on group. This result is in accordance with Özkurt et al (2010)⁽²⁷⁾, who observed adhesive/cohesive failure in the zirconia base ceramics they used.

The press-on group showed cohesive failure, which might be due to the nature of pressed veneer ceramic, as it was weaker and more easily delaminated than the high-strength CAD-on veneer. This result agrees with Tsalouchou et al (2008)⁽¹³⁾, who found mainly cohesive failure within the pressing veneer materials they used.

Regarding biaxial flexural strength, the results revealed no statistically significant difference between CAD-on and Press-on techniques. This result might be related to microstructural nature of the supported zirconia core material. Such findings are consistent with Lin et al (2012)⁽¹¹⁾, who found that different fabrication techniques (heat-pressed and CAD/CAM) do not affect the biaxial flexural strength. Yilmaz et al (2011) showed a similar biaxial flexural strength recorded at the bottom surface of bilayer zirconia specimens^(5,8). Eisenbuger et al (2011)⁽³⁾ found no significant difference in fracture load between layering and press-on techniques when a zirconia core was used.

In all ceramic systems, the flaw population (size, number and distribution) can be related to the material or affected by the fabrication process. Thus, it might be expected that heat pressing and sintering might introduce significantly fewer flaws, resulting in good strength properties, as both techniques are controllable procedures⁽¹⁹⁾. Industrially

produced ceramic blanks used for the fabrication of veneers show fewer faults compared to manually produced veneers. CAD/CAM process uses a high-quality material with a minimum of flaws.

Although there is a lack of studies assessing the fracture load of zirconia restorations veneered using CAD/CAM machined lithium disilicate ceramics, studies are confirming that lithium disilicate ceramic CAD/CAM crowns may be an effective option for all-ceramic crowns⁽²⁸⁾. Schmitter et al (2012)⁽⁷⁾ demonstrate that crowns made of zirconia frameworks veneered with CAD/CAM-manufactured lithium disilicate ceramics display a higher fracture resistance than manually veneered crowns.

Compared with the conventional powder/liquid layering technique for zirconia core material, Aboushelib et al, (2008)⁽²⁹⁾ showed that heat-pressed veneering porcelain produces significantly higher fracture strength when pressed to a zirconia core. Also Lin et al, (2012)⁽¹¹⁾ revealed that the heat-pressed technique provided significantly high flexural strength for the zirconia bilayer specimens. Fischer et al, (2008)⁽¹⁴⁾ stated that, to realize the benefit of high-strength zirconia as a framework, veneering ceramic has to be strengthened.

Conclusions:

Within the limitations of this in vitro study, the following conclusions were drawn:

- The veneering technique affected the shear bond strength between the zirconia core and veneering ceramic.
- The CAD-on technique demonstrated significantly higher shear bond strength than the Press-on technique.
- All CAD-on specimens exhibited mixed adhesive/cohesive failure, whereas all Press-on specimens exhibited cohesive failure within the veneering ceramic.
- The CAD-on group demonstrated a numerically higher mean biaxial flexural strength than the Press-on group; however, this difference was not statistically significant ($p=0.26$).

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

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