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COVER STORY

Fracture resistance of computer-aided design and computer-aided manufacturing ceramic crowns cemented on solid abutments

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ABSTRACT

Background. Because no information was found in the dental literature regarding the fracture resistance of all-ceramic crowns using CEREC (Sirona) computer-aided design and computer-aided manufacturing (CAD-CAM) system on solid abutments, the authors conducted a study.

Methods. Sixty synOcta (Straumann) implant replicas and regular neck solid abutments were embedded in acrylic resin and randomly assigned (n = 20 per group). Three types of ceramics were used: feldspathic, CEREC VITABLOCS Mark II (VITA); leucite, IPS Empress CAD (Ivoclar Vivadent); and lithium disilicate, IPS e.max CAD (Ivoclar Vivadent). The crowns were fabricated by the CEREC CAD-CAM system. After receiving glaze, the crowns were cemented with RelyX U200 (3M ESPE) resin cement under load of 1 kilogram. For each ceramic, one-half of the specimens were subjected to the fracture resistance testing in a universal testing machine with a crosshead speed of 1 millimeter per minute, and the other half were subjected to the fractured resistance testing after 1,000,000 cyclic fatigue loading at 100 newtons.

Results. According to a 2-way analysis of variance, the interaction between the material and mechanical cycling was significant ($P = .0001$). According to a Tukey test ($\alpha = .05$), the fracture resistance findings with or without cyclic fatigue loading were as follows, respectively: CEREC VITABLOCKS Mark II (405 N/454 N) was statistically lower than IPS Empress CAD (1169 N/1240 N) and IPS e.max CAD (1378 N/1025 N) ($P < .05$). The IPS Empress CAD and IPS e.max CAD did not differ statistically ($P > .05$). According to a *t* test, there was no statistical difference in the fracture resistance with and without cyclic fatigue loading for CEREC VITABLOCS Mark II and IPS Empress CAD ($P > .05$). For IPS e.max CAD, the fracture resistance without cyclic fatigue loading was statistically superior to that obtained with cyclic fatigue loading ($P < .05$).

Conclusions. The IPS Empress CAD and IPS e.max CAD showed higher fracture resistance compared with CEREC VITABLOCS Mark II. The cyclic fatigue loading negatively influenced only IPS e.max CAD.

Practical Implications. The CEREC VITABLOCS Mark II, IPS Empress CAD, and IPS e.max CAD ceramic crowns cemented on solid abutments showed sufficient resistance to withstand normal chewing forces.

Key Words. CAD-CAM; ceramics; abutments; fracture resistance; implant.
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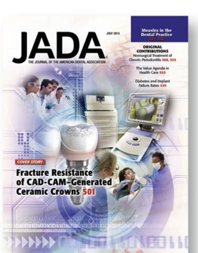
The success of implant-supported prosthetic rehabilitation, under the technical point of view, is directly related to key parameters such as the size of the crown, the implant position, the habits of the patient, the number of missing elements, and the type of denture.[1,2] The long treatment required for osseointegration and the rehabilitation with a prosthesis can be cited as disadvantages.[3] Thus, for the professional, the great challenge is in selecting the materials and techniques that reduce the time required to treat the patient.



One of the most important elements in treating a patient who receives an implant-supported prosthesis is the selection of prosthetic components, which involves assessing needs regarding the

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ease of fabrication, cost, esthetics, occlusion, effects of implant position on periodontal status, need for temporary restoration, type of restorative material that will be used, clinical performance, and implant type to which it is connected.[4]

The unit prosthesis on implants can be screwed or cemented in, and the attachment choice can affect the force transmitted to the components and to the bone-implant interface.[5] The screwed-in restorations have the main advantage of possibly being removed if necessary after installed, but they have an increased risk of fracture and microcracks in the ceramic,[5,6] a risk of bacterial contamination, esthetic problems,[5] and a chance for screw loosening.[7,8] Cemented restorations have the disadvantage of being permanent; however, they tend to be more resistant and have better esthetics, the loosening of screws is less frequent, and the cement acts as a biological seal to help prevent contamination.[4]

With the development of dental implants, a significant advancement in computer-aided design and computer-aided manufacturing (CAD-CAM) technology has shortened a series of laboratory and clinical steps for rehabilitating patients' dentitions with dental implants. Through the use of this technology, professionals can design and manufacture custom esthetic abutments and all-ceramic crowns. Impression procedures have become optional. The development of CAD-CAM tools allows the dentist to perform long laboratory procedures in 1 day.[9,10]

Studies show that the prosthetic structures produced by CAM-CAM systems present results at least as good as those obtained by conventional methods.[11,12] This may in part be explained by the manufacturing process of the ceramic for CAD-CAM technology, which significantly reduces or even eliminates internal porosity. However, the high survival rates of crowns in the CAD-CAM system on natural teeth prove that the tooth crown and roots behave as a single body.[12] As with the components of dental implants, solid abutments make the implant and abutment a unique body, which would solve problems such as loosening, screw breakage, and thread damage that occur with some frequency in screwed abutments.[13]

Despite the assumption of behavior similar to natural teeth, questioning whether it is possible to use CAD-CAM prostheses on solid abutments still remains unanswered. The simplified use of this technique may facilitate reduced time for the doctor-patient consultation and satisfy, to the highest degree, the esthetic needs of the patient.[14] Also, this technique eliminates the use of metallic structures on the crown. However, in relation to the restorative material, there remains an open question: which ceramic material would behave better mechanically when cemented on the solid metal abutment?

We conducted a study to evaluate the fracture resistance of ceramic crowns made by the CAD-CAM CEREC system (Sirona) cemented on solid abutments, using variables such as the type of ceramic and the influence of cyclic fatigue loading on fracture resistance of these restorations. Our study was conducted under 2 hypotheses: there are statistical differences in fracture resistance among the ceramic materials and the cyclic fatigue loading influences the fracture resistance of the ceramic crowns.

METHODS

For the study, 60 regular neck (RN) implant analogs and RN synOcta solid abutments (Straumann), 4 millimeters in height, were used. Each body was embedded in acrylic resin, simulating an osseointegrated implant, because its mode of elasticity is similar to that of bone tissue.[15,16] The 35-newton tightening torque was applied on the pillars. The samples were randomly divided into 6 groups of 10 elements each in accordance with the literature.[11,17,18]

The crowns were made by CAD-CAM using CEREC software (Version 4.0.2, Sirona Dental Systems). The abutment received the VITA Powder Scan Spray (VITA Zahnfabrik) to create an opaque surface needed for scanning by an optical 3-dimensional intraoral camera, creating a 3-dimensional virtual model. The shape of the crowns was designed with an individual biogeneric copy from a right second premolar. The thickness of the ceramic restoration in the occlusal face was 1.6 mm, 2.0 mm in the proximal surfaces, and 3.0 mm in the buccal and palatal faces (Figure 1). The die spacer used was 50 micrometers.

Sixty crowns were fabricated in the milling unit: 20 in feldspathic ceramic (CEREC VITABLOCS Mark II, VITA); 20 in leucite-reinforced glass ceramic (IPS Empress CAD, Ivoclar Vivadent); and 20 in lithium disilicate-reinforced glass-ceramic (IPS e.max CAD, Ivoclar Vivadent). The crowns milled in IPS e.max were crystallized in a ceramic furnace (Programat P300, Ivoclar Vivadent) for 30 minutes at a final temperature of 850°C under vacuum. After removal of the sprue and polishing with rubber tips (DiaGloss, Edenta) at 12,000 revolutions per minute at low speed, all ceramics were glazed: the IPS Empress CAD and CEREC VITABLOCS Mark II at a temperature of 790°C, and the IPS e.max at 770°C.

The inner surface of the crowns was etched with 10% hydrofluoric acid Dentsply Porcelain Conditioner (Dentsply). The CEREC VITABLOCS Mark II (feldspathic) crowns received conditioning for 2 minutes, the IPS Empress CAD (leucite) crown for 1 minute, and the IPS e.max CAD (lithium disilicate) crown for 20 seconds. Different conditioning times for the 3 ceramics seem to be most successful to increase the surface area available for bonding.[19] After conditioning, all

ABBREVIATION KEY. CAD-CAM: Computer-aided design and computer-aided manufacturing. **LED:** Light-emitting diode. **RN:** Regular neck.

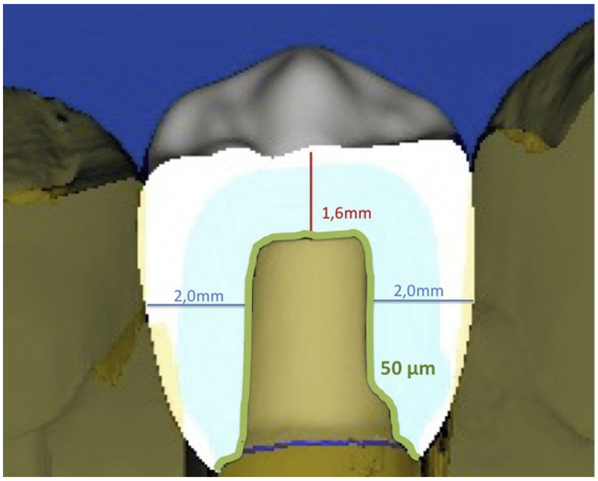

Figure 1. Representative picture of the dimensions of the ceramics crowns in the inLab software (CEREC). mm: Millimeter. µm: Micrometer.

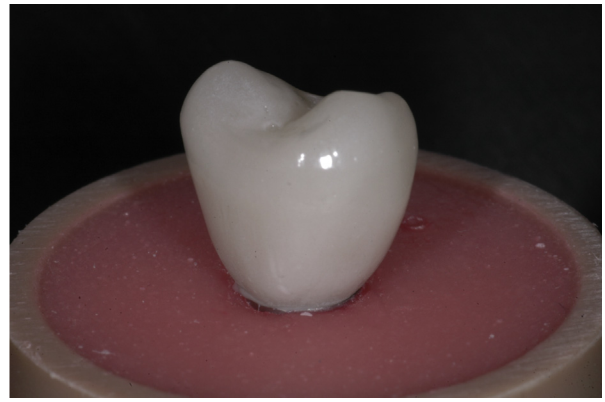

Figure 2. Crown cemented on solid abutment.

crowns were rinsed for 20 seconds and submerged in an ultrasonic tank in distilled water for 5 minutes to remove impurities. After drying, a layer of silane (Ceramic Primer, 3M ESPE) was applied, followed by gentle air for 5 seconds.

Cementation was performed with the resin cement RelyX U200 (3M ESPE) according to the manufacturer's instructions. The crown was cemented onto the abutment with the aid of a specific device with which a cementing load of 1 kilogram for 3 minutes was standardized. Excess cement was removed with a microbrush, followed by photoactivation by light-emitting diode (LED) (Bluephase, Ivoclar Vivadent) for 60 seconds on each side, with more than 1,000 milliwats per square centimeter intensity. Energy intensity was monitored every 5 specimens with the aid of an LED Radiometer Light Curing Meter (SDI). The specimens (Figure 2) were stored in distilled water at 37°C for 24 hours. After the time elapsed, 10 specimens were subjected to the fracture-resistance testing and the other 10 received the cyclic fatigue loading, followed by the fracture resistance testing.

Mechanical cycling testing. The specimens were submitted to cyclic fatigue-loading cycling machine (ER-11000, Erios). The load profile shape was a sine wave placed always in contact mode on the occlusal surface of the crowns at 100 N using 1,000,000 cycles at 1 hertz in distilled water at 37°C.[20]

At the end of the cyclic fatigue loading, the presence or absence of cementation failures, fractures, chips, or cracks on the ceramic crowns was observed with the aid of a 10x loupe SF 10 (Olympus), and each issue was designated by 1 of 3 classifications: success (unchanged); fails (fractures, chips, or cracks); or survival (some kind of failure, but without interfering with the esthetics and even the use of the restoration).[11]

Fracture resistance testing. The fracture resistance testing was performed in a universal testing machine (DL-2000, EMIC) using a cell load of 10 kilonewtons and a crosshead speed of 1 mm/min. A 6-mm–diameter metal sphere was attached to the cell load connected to the mobile arm of the testing machine. The metal sphere was left in contact with the buccal and palatal cuspal inclines. The compression load was applied parallel to the long axis of the crown until the fracture occurred. The maximum force was recorded in newtons.

Failures analysis. After the fracture resistance testing, the specimens were visually assessed with the aid of a 10x loupe SF 10 (Olympus) to determine the type of failure: cracks, chips, or fractures in the ceramic. Also, the cement retention on solid abutment or ceramic surface was evaluated.

Statistical analysis. The fracture resistance values were submitted to the Kolmogorov-Smirnov normality test. As there was normality, the results were analyzed by 2-way analysis of variance (ANOVA) to test the effect of the ceramic material and the cyclic fatigue loading on the fracture resistance. Furthermore, a *t* test was used to determine differences in fracture resistance with and without cyclic fatigue loading in each ceramic. The significance level was $P = .05$. The statistical software used was SPSS 10.0 (SPSS).

RESULTS

According to 2-way ANOVA, the material factor was significant ($P = .0001$), and the cyclic fatigue loading factor was not significant ($P = .084$). The interaction between the material and cyclic fatigue loading was significant ($P = .0001$). Tukey and *t* tests were used to complement the ANOVA. The Tukey test compared fracture resistance between the 3 ceramics with and without cyclic fatigue loading, and the *t* test was used to determine differences in fracture resistance with and without cyclic fatigue loading in each ceramic.

TABLE

Mean fracture resistance (newtons) and standard deviations of the groups with and without cyclic fatigue loading.

GROUP	WITHOUT CYCLIC FATIGUE LOADING (NEWTONS)*	WITH CYCLIC FATIGUE LOADING (NEWTONS)*	P VALUE
CEREC VITABLOCS Mark II (VITA)	405 (60)^{Aa}	454 (77)^{Aa}	.1340
IPS Empress CAD (Ivoclar Vivadent)	1,169 (267)^{Bb}	1,240 (180)^{Bb}	.4980
IPS e.max CAD (Ivoclar Vivadent)	1,378 (234)^{Ba}	1,025 (87)^{Bb}	.0001

* Means followed by the same uppercase letter in the columns do not differ statistically according to Tukey test at a significance level of .05; means followed by the same lowercase letter in the lines do not differ statistically according to a *t* test at a significance level of .05.

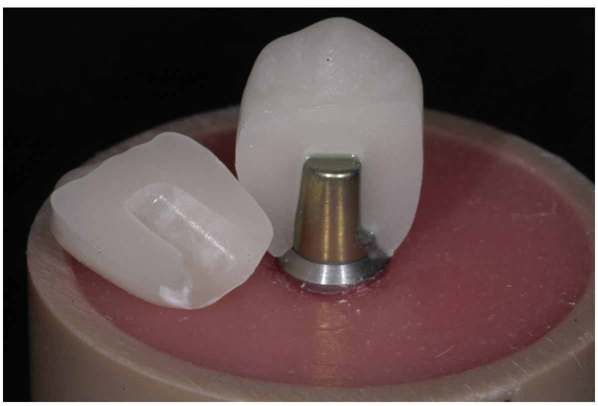

Figure 3. Pattern of failure of the ceramic after the mechanical testing.

The table shows the means of fracture resistance for the different groups.

The ceramic CEREC VITABLOCS Mark II, with and without cyclic fatigue loading, obtained a mean fracture resistance statistically lower than the ceramics IPS Empress CAD and IPS e.max CAD ($P < .05$). IPS Empress CAD and IPS e.max CAD did not differ statistically ($P > .05$) in terms of mean fracture resistance with and without cyclic fatigue loading.

According to a *t* test, no statistical difference was detected applying the cyclic fatigue loading for CEREC VITABLOCS Mark II and IPS Empress CAD ($P > .05$). For ceramic IPS e.max CAD, the mean fracture resistance without cyclic fatigue loading was statistically higher than that obtained with cyclic fatigue loading ($P < .05$).

After the cyclic fatigue loading, no specimen showed cementation failures, fractures, chips, or cracks in the ceramic crown.

After the fracture-resistance testing, all failures were cohesive in ceramics. The fractures occurred in the mesiodistal direction of the crowns, up which there was the flat side (slot) of the abutment dividing the buccal and lingual portions of the crowns (Figure 3). Resin cement remnants on the abutments were not observed.

DISCUSSION

Dental ceramics were developed to restore teeth affected by caries and fractures. With the emergence of implants and esthetic necessity, ceramics have been the solution for fast and efficient rehabilitation. However, the elastic modulus of titanium is much higher than that of the tooth tissue.[21] Consequently, the data regarding fracture resistance of esthetic ceramic crowns cemented on teeth may not be applied to crowns cemented on titanium abutments. In addition to the different physical properties of the abutments, it is believed that the fracture resistance of ceramic crowns may be affected by the occlusal thickness of the crown, the composition of the abutment, the method of cementation, the type of cement, and the height of the abutment.[15] For these reasons, this study standardized all variables except the ceramic material.

Our study evaluated the fracture resistance of ceramic crowns made using the CAD-CAM system that were cemented onto solid abutments. According to the results, the hypothesis that there is a difference in fracture resistance among ceramics was accepted because the CEREC VITABLOCS Mark II ceramic crowns showed lower fracture resistance compared with IPS Empress CAD and IPS e.max CAD ceramic crowns. The study by Charlton and colleagues[22] found that the CEREC VITABLOCS Mark II presented flexural strength of 94 megapascals, tensile modulus of 8.65 gigapascals, and toughness of 1.37 MPa $\times$ meters$^{1/2}$, lower values than those found for the ceramic IPS Empress CAD, which corresponded to 137 MPa, 16.10 GPa, and 2.18 MPa $\times$ m$^{1/2}$, and IPS e.max CAD 360 MPa and 2.25 MPa $\times$ m$^{1/2}$, respectively. Therefore, the lower fracture resistance of CEREC VITABLOCS Mark II crowns can be explained by the fact that the feldspathic ceramic has less intrinsic resistance compared with the other 2 ceramics that are considered reinforced ceramics.[23] In addition to that, CEREC VITABLOCS Mark II ceramic crowns were etched with 10% hydrofluoric acid for 2 minutes, instead of 4.9% hydrofluoric acid for 1 minute as recommended by the manufacturer. Hydrofluoric acid concentration and etching time influence the surface modification of feldspathic ceramic and could have a weakening effect on the strength of the material.[24] Therefore, the etching protocol applied in the present study cannot be excluded as a possible negative effect in the fracture resistance values of CEREC VITABLOCS Mark II ceramic crowns, once it was twice the recommended acid concentration and etching time.

The ceramic IPS Empress CAD is a leucite-reinforced glass-ceramic and has 35% to 45% volume of the crystals of leucite with an average size of 1 to 5 µm. The IPS e.max CAD is also a glass-ceramic containing 70% of lithium disilicate crystals by volume.[25] Because the IPS e.max CAD shows greater intrinsic resistance compared with ceramic IPS Empress CAD,[26] the expectation was that the crowns made of IPS e.max CAD would present greater fracture resistance. However, the results showed no statistical difference in the values of fracture resistance for both reinforced ceramics. A possible explanation for this finding may be the fact that the 2 reinforced ceramics were evaluated in the form of cemented crowns on solid abutments using the adhesive cementation technique, and not only through samples in the form of bars or disks that are used by different mechanical tests.[27] Stawarczyk and colleagues[28] found that the IPS Empress CAD crowns cemented with resin cement RelyX Unicem (3M-ESPE) on metal abutments had higher fracture resistance compared with those using glass ionomer cement. However, for the IPS e.max CAD crowns, the cementing agent did not influence the fracture resistance of these restorations. The study by Bindl and colleagues[29] also showed that the adhesive cementation contributed to equate the values of fracture resistance of leucite-reinforced glass-ceramic (ProCAD, Ivoclar Vivadent) or lithium disilicate-reinforced glass-ceramic (VP 2297, Ivoclar Vivadent). Therefore, adhesive cementation with RelyX U200 resin cement could be a possible explanation for the increase in fracture resistance of the IPS Empress CAD crowns to the point of reaching the values of the IPS e.max CAD crowns. Cyclic fatigue loading is an in vitro methodology that tries to simulate the masticatory loads applied on the restorations. In our study, ceramic crowns were submitted to cyclic fatigue loading at 100 N using 1,000,000 cycles, simulating 4 years in function.[30-32] For the 3 materials, the cyclic fatigue loading did not cause cementation failure, fractures, chips, or cracks on the ceramic crown. The fracture resistance before and after cyclic fatigue loading did not differ statistically for the CEREC VITABLOCS Mark II and IPS Empress CAD, but only for the IPS e.max CAD, being the accepted second hypothesis. The small increase in fracture resistance after cyclic fatigue loading for the CEREC VITABLOCS Mark II and IPS Empress CAD is considered coincidental, which corroborates the fact that the mechanics for 1,000,000 cycles did not affect the intrinsic structure and caused no deleterious effect on these ceramics. For IPS e.max CAD crowns, there was a 25% reduction in fracture resistance after cyclic fatigue loading.

In this study, the cyclic fatigue loading was conducted with samples immersed in water. Even though the ceramic blocks used for the machining process in CAD-CAM contain fewer imperfections,[33] ceramic materials have flaws and surface defects, which are sealed by glazing, favoring the increased strength of the material.[34] These faults and surface defects are directly related to the initial sites that lead to fractures of the ceramic when masticatory loads are applied.[22] Therefore, a possible cause of reduced resistance of ceramics is the kinetics of slow propagation of faults or cracks in the ceramic surface that can occur during mechanical cycling in water. The slow crack propagation can be attributed to the presence of moisture inside the possible sites of fracture, which chemically degrades ceramics, being strongly influenced by the amount and composition of the glassy phase of the ceramic microstructure. This phenomenon occurs preferentially in silicate-based glass, resulting in the rupture of the chemical bonds between silicon and oxygen stress corrosion.[35] Although there are no published data that justifies a reduction in fracture resistance of the IPS e.max CAD after cyclic fatigue loading, it is speculated that the cyclic fatigue loading associated with moisture may have had some effect on the chemical bonds in the glassy matrix of the IPS e.max CAD. This ceramic has a baking process different from the others. A block of IPS e.max CAD is milled at an intermediate stage, during which lithium metasilicate—which corresponds to 40% of 0.5 µm crystals by volume—is precipitated. In this phase, the material exhibits a bluish color and little chemical durability. Through a thermal crystallization process at 850°C, the lithium metasilicate is transformed into a lithium disilicate, which corresponds to 70% by volume of crystals with a size of 3 to 6 µm, which provides mechanical strength and optical properties of glass ceramics. However, further research regarding possible causes justifying the reduction of resistance of this ceramic after cyclic fatigue loading is necessary.

Associated with the values of fracture resistance, it is also important to analyze the types of fractures in each experimental group. This is not only because the result of the fracture resistance ensures a material or technique is ideal for restoring a tooth structure, but also because the result will show what kind of failure will occur, that is, if the prognosis is favorable or not. All crowns fractured similarly; in each case—regardless of the material—the crowns fractured with cohesive failures in the ceramic, mesiodistally dividing the crown in buccal and palatal parts, although the abutment remained intact. Usually 1 part remained attached to the abutment, similar to the findings in a study reported by Bindl and colleagues.[12] This type of failure was shown with the steel ball of 6 mm diameter that was adapted to the buccal and palatal cuspal inclines of the crown. The load applied on the crown favored the external displacement of the buccal and palatal cusps, with a tension concentration in the top of the abutment and a fracture line in the mesiodistal direction. Another factor that favored the type of fracture of the ceramic crowns was the design of the abutment. The abutment has a mild taper of 6° and a flat face (slot) that serves to stabilize the crown, preventing rotations, besides serving as a position indicator. Moreover, the angles are obtuse between the abutment and the implant base, which increases the tension of the ceramic in this region and can be a propagator site of fracture.[11] It is also important to emphasize that the abutments did not have resin cement remnants. It is believed that this finding is related to the fact that no treatment of the solid metal abutment with specific primers was done in our study. These primers increase the bond of the resin cement to the metal abutment, and as a consequence, parts of the resin cement tend to stay attached to the abutment after the fracture resistance test.[15]

The results of fracture resistance in all ceramic crowns, regardless of the type of application of cyclic fatigue loading, were better than the normal masticatory forces applied on premolar teeth, which correspond to values of 100 N to 300 N,[8,30,36] with restriction for patients with bruxism, for which the load values are between 500 N and 800 N.[37]

Transfer of the results of laboratory studies to the clinic must be done with caution because in vitro studies cannot reproduce the real situation in the oral cavity. However, according to the results obtained, it can be suggested that the CEREC VITABLOCS Mark II, IPS Empress CAD, and IPS e.max CAD ceramic crowns cemented on solid abutments showed sufficient resistance to withstand normal chewing forces. To determine the type of ceramic to be used, it is important that the clinician take into account patient characteristics such as age, presence of parafunctional habits, and chewing strength, as well as the cost of the ceramic blocks. Another feature that should be noted is a gingival condition. If the implant is markedly subgingival, it can hamper the scanning technique. To solve this problem, bulkier healings caps should be adapted on RN implants.

This study showed that CAD-CAM is a promising technique for the fabrication of monolithic crowns directly on solid abutments, restoring function and esthetics in a single appointment. The same conclusion was not obtained in another study,[17] in which the authors advised not to use this technique. Possibly, the different findings are linked to the methodology. In that study,[17] the crowns were cemented on a cementable abutment, which contained a hole for the screw, and not a solid abutment as in the our study. One can speculate that solid abutments transmit chewing forces more evenly than a hollow abutment. However, longitudinal clinical studies are needed to confirm this assumption.

CONCLUSIONS

In this in vitro study, we concluded that ceramic IPS Empress CAD and IPS e.max CAD obtained higher fracture resistance on solid abutments compared with CEREC VITABLOCS Mark II. In addition, the cyclic fatigue loading negatively influenced only the ceramic IPS e.max CAD. ■

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