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RESEARCH AND EDUCATION

Comparison of wear and fracture resistance of additively and subtractively manufactured screw-retained, implant-supported crowns

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ABSTRACT

Statement of problem. Additively manufactured resins indicated for fixed definitive prostheses have been recently marketed. However, knowledge on their wear and fracture resistance when fabricated as screw-retained, implant-supported crowns and subjected to artificial aging is limited.

Purpose. The purpose of this in vitro study was to evaluate the volume loss, maximum wear depth, and fracture resistance of screw-retained implant-supported crowns after thermomechanical aging when fabricated using additively and subtractively manufactured materials.

Material and methods. Two additively manufactured composite resins (Crowntec [CT] and VarseoSmile Crown Plus [VS]) and 2 subtractively manufactured materials (1 reinforced composite resin, Brilliant Crios [BC] and 1 polymer-infiltrated ceramic network, Vita Enamic [EN]) were used to fabricate standardized screw-retained, implant-supported crowns. After fabrication, the crowns were cemented on titanium base abutments and then tightened to implants embedded in acrylic resin. A laser scanner with a triangular displacement sensor (LAS-20) was used to digitize the preaging state of the crowns. Then, all crowns were subjected to thermomechanical aging (1.2 million cycles under 50 N) and rescanned. A metrology-grade analysis software program (Geomagic Control X 2020.1) was used to superimpose postaging scans over preaging scans to calculate the volume loss (mm^3) and maximum wear depth (mm). Finally, all crowns were subjected to a fracture resistance test. Fracture resistance and volume loss were evaluated by using 1-way analysis of variance and Tukey Honestly significant difference (HSD) tests, whereas the Kruskal-Wallis and Dunn tests were used to analyze maximum wear depth. Chi-square tests were used to evaluate the Weibull modulus and characteristic strength data (α=.05).

Results. Material type affected the tested parameters (*P* .001). CT and VS had higher volume loss and maximum wear depth than BC and EN (*P* .001). EN had the highest fracture resistance among tested materials (*P* .001), whereas BC had higher fracture resistance than CT (*P*=.011). The differences among tested materials were not significant when the Weibull modulus was considered (*P*=.199); however, VE had the highest characteristic strength (*P* .001).

Conclusions. Additively manufactured screw-retained, implant-supported crowns had higher volume loss and maximum wear depth. All materials had fracture resistance values higher than the previously reported masticatory forces of the premolar region; however, the higher characteristic strength of the subtractively manufactured polymer-infiltrated ceramic network may indicate its resistance to mechanical complications. (J Prosthet Dent xxxx;xxx:xxx-xxx)

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Clinical Implications

Screw-retained, implant-supported crowns fabricated using the tested additively manufactured definitive composite resins may be suitable alternatives for premolar implant-supported restoration. However, considering their higher wear and lower fracture resistance values, they may be more prone to long-term mechanical complications, especially with the Crowntec product.

Implant-supported prostheses have become a commonly preferred treatment option to replace single missing posterior teeth[1,2] because of their high survival rate of up to 98.3%.[3] Retention is critical for the success of an implant-supported prosthesis, with different retention mechanisms being described,[4] and with the choice based mainly on the clinical situations.[5] Screw- and cement-retained prostheses have both been popular and present different advantages in terms of esthetics, passivity, and retrievability;[6,7] this has led to the introduction of different combined designs.[2] An alternative design is to cement screw-retained crowns onto titanium base (Ti-base) abutments and then tighten them intraorally.[4,8]

The restorative material affects the clinical success of an implant-supported prosthesis.[9] Advances in computer-aided design and computer-aided manufacturing (CAD-CAM) technology have facilitated the use of restorative materials with different mechanical and chemical properties.[10–12] Among them, resin-based materials have the advantage of having a low elastic modulus[13] and have been reported to compensate for the damping effect of the periodontal ligament that is absent in implants.[1] Even though subtractive manufacturing has been used to fabricate prostheses based on resin materials,[14–16] additive manufacturing has recently become an option with the introduction of printable composite resins marketed for definitive restorations.[10,17–21]

Among the studies on additively manufactured composite resin crowns,[10,17–19,21–24] the authors are aware of only 1 study that evaluated their fracture resistance when fabricated as an implant-supported crown.[25] However, that study was based on cement-retained crowns and did not subject them to thermomechanical aging.[25] Considering that prosthetic design may affect the fracture resistance of implant-supported prostheses,[4] it is essential to evaluate additively manufactured composite resins in different situations and under different external stresses to broaden knowledge on their applicability. In addition, a restorative material should have resistance to wear, which is the loss of material from the surface,[26,27] similar to that of dental enamel.[28,29] Therefore, the present study aimed to compare the occlusal surface wear and fracture resistance of screw-retained, implant-supported crowns cemented on Ti-base abutments fabricated by using additively and subtractively manufactured resin-based materials. The null hypotheses were that material type would not affect the volume loss, maximum wear depth, or fracture resistance of screw-retained implant-supported crowns after thermomechanical aging.

MATERIAL AND METHODS

Figure 1 shows an overview of the study and detailed information on the additively (Crowntec [CT]; Saremco and VarseoSmile Crown Plus [VS]; Bego), subtractively (Brilliant Crios [BC]; Coltène AG and Vita Enamic [EN]; Vita Zahnfabrik) manufactured materials tested and presented in Table 1. A Ti-base abutment (grade 5, 3 mm in height, Trias Implants; Servo-Dental GmbH & Co KG) was digitized by using the manufacturer's proprietary scan body (CAD-CAM Ti-base Scan Body; Servo-Dental GmbH & Co KG) and a laboratory scanner (inEos X5; Dentsply Sirona). A maxillary right first premolar crown with a screw access channel was designed by using a dental design software program (DentalCAD 3.1 Rijeka; exocad GmbH) in standard tessellation language (STL) format.

Before the study, a power analysis was performed, and 10 specimens per group were deemed sufficient ($f=0.90$, $1-\beta=95\%$, $\alpha=.05$).[10] To fabricate CT and VS crowns, the design STL file was transferred into a nesting software program (Composer v1.3; ASIGA) and placed with its occlusal surface facing the build platform. After generating supporting structures automatically and removing any supports at critical areas (margins, screw access channel, and intaglio surface), this design was duplicated for standardization. The supporting structures had a minimum height of 2 mm, a maximum width of 1.5 mm, and a self-support angle of 30 degrees. A digital light processing-based 3-dimensional (3D) printer (MAX UV; ASIGA) was used to fabricate the crowns with a 50-µm layer thickness, and the zero position of the printer was calibrated according to recommendations before fabricating each set of specimens. After fabrication, residual resin on the CT crowns was cleaned with 96% alcohol-soaked cloth, whereas VS crowns were cleaned in an ultrasonic bath containing 96% ethanol solution for a total of 5 minutes (3 minutes of precleaning in reusable ethanol and 2 minutes of cleaning in fresh ethanol). After cleaning, all crowns were dried with an air syringe. CT crowns were then placed in a xenon polymerization device (Otoflash G171; NK Optik) and polymerized under nitrogen oxide gas atmosphere (2000 × 2 lighting

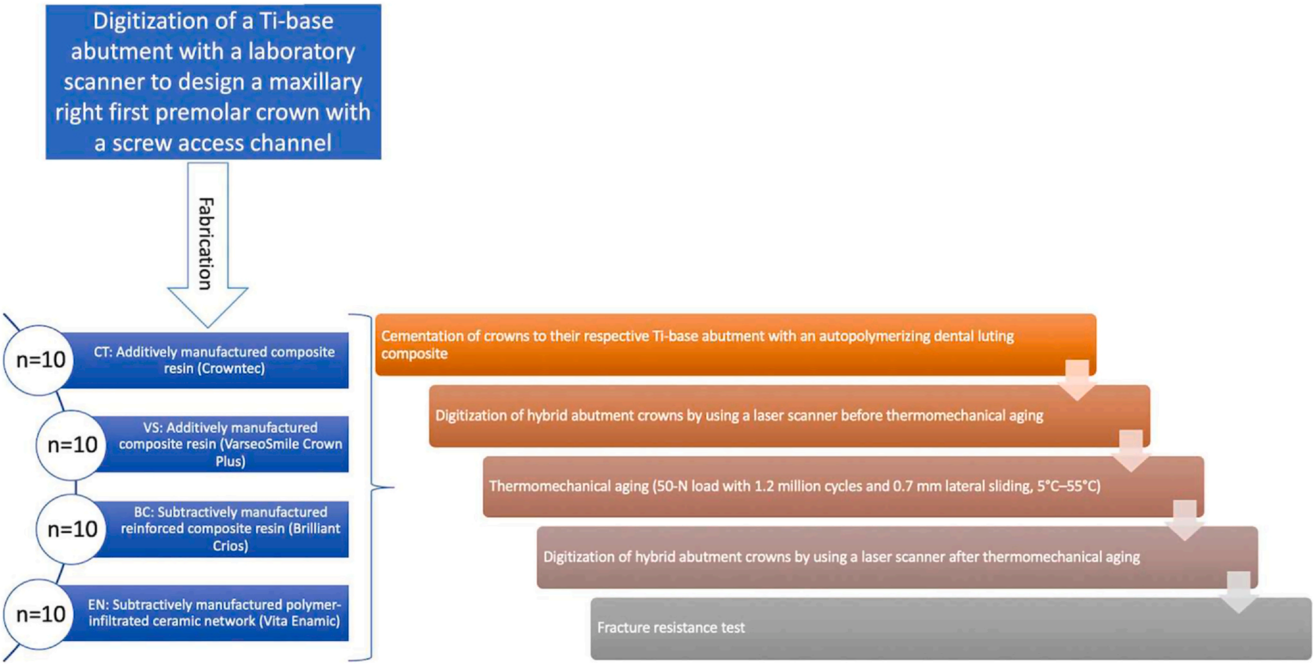


Figure 1. Study design. BC, Brilliant Crios; CT, Crowntec; EN, Enamic; VS, VarseoSmile Crown Plus.

Table 1. Materials tested

Material	Type	Composition	Manufacturer
Crowntec (CT, LOT D934)	Additively manufactured composite resin	Esterification products of 4,4′-isopropylidiphenol, ethoxylated and 2-methylprop-2-enoic acid, silanized dental glass, pyrogenic silica, initiators. Total content of inorganic fillers (particle size 0.7 µm) is 30-50 wt%.	Saremco Dental AG
VarseoSmile Crown Plus (VS, LOT 601028)	Additively manufactured composite resin	Esterification products of 4,4′-isopropylidiphenol, ethoxylated and 2-methylprop-2enoic acid, silanized dental glass, methyl benzoylformate, diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide, 30-50 wt%—inorganic fillers (particle size 0.7 µm)	Bego
Brilliant Crios (BC, LOT J69904)	Subtractively manufactured reinforced composite resin	70.7 wt% barium glass (< 1 µm) and amorphous silica (SiO_2; < 20 nm), Cross-linked methacrylates (Bis-GMA, Bis-EMA, TEGDMA)	Coltène AG
Vita Enamic (EN, LOT 99430)	Subtractively manufactured polymer-infiltrated ceramic network	14 wt% Methacrylate polymer (UDMA, TEGDMA) and 86 wt% fine-structure feldspathic ceramic network	Vita Zahnfabrick

Bis-GMA, Bisphenol A-glycidyl methacrylate; Bis-EMA, Ethoxylated bisphenol A-dimethacrylate; TEGDMA, Triethylene glycol dimethacrylate; UDMA, Urethane dimethacrylate.

exposures), which was followed by airborne-particle abrasion of the external surfaces with 50-µm glass beads (Rolloblast; Renfert) at 0.15 MPa and removal of the supports with a cut-off wheel. The supports of VS crowns were removed first by using the same cut-off wheel, and the external surfaces were airborne-particle abraded with 50-µm glass beads (Rolloblast; Renfert) at 0.15 MPa until the whitish layer that appeared after cleaning had disappeared. Thereafter, VS crowns were placed in the same xenon polymerization device and polymerized under nitrogen oxide gas atmosphere (1500 × 2 lighting exposures).[30,31]

To fabricate BC and EN crowns, the design STL was transferred into a nesting software program (CEREC inLab CAM v22; Dentsply Sirona), and crowns were fabricated using a 5-axis milling device (CEREC inLab MCXL; Dentsply Sirona). After fabrication, the supports were removed by using a cut-off wheel (Keystone Cut-off Wheels; Keystone Industries) and washed in an ultrasonic cleaner. External surfaces of all crowns were smoothed under ×3.5 magnification optical loupes (EyeMag Pro; Carl Zeiss) with a small round bur (Round carbide bur; Glin Medical). Thereafter, the intaglio surfaces of the crowns were treated according to the respective manufacturer's recommendations (Table 2).

Forty dental implants (Trias Implants Ø3.8 ×12 mm; Servo-Dental GmbH & Co KG) were embedded in a plastic cylinder containing autopolymerizing acrylic resin (SC; Imicryl), with a 3-mm gap between the implant neck and the resin surface, by using stainless steel

Table 2. Surface treatment of tested materials

Material	Surface Treatment
Crowntec	Airborne-particle abrasion with 110-µm aluminum oxide (Korox; Bego) for 10 s at 0.15-MPa and 10 mm distance
VarseoSmile Crown Plus	Airborne-particle abrasion with 50-µm aluminum oxide (Cobra; Renfert) for 10 s at 0.2 MPa and 10 mm distance
Brilliant Crios	Airborne particle abrasion with 50-µm aluminum oxide (Cobra; Renfert) for 10 s at 0.15-MPa and 10 mm distance
Vita Enamic	4.5% hydrofluoric acid (IPS Ceramic Etching Gel; Ivoclar AG) etching for 60 s

plates.[4] Proprietary Ti-base abutments of the implant manufacturer were tightened to each implant to 30 Ncm by using a torque wrench (Torque ratchet 10-40 Ncm; Servo-Dental GmbH & Co KG) and were retightened after 10 minutes to accommodate embedment relaxation.[8] The external surfaces of the Ti-base abutments were then airborne-particle abraded with 50-µm aluminum oxide (Cobra; Renfert) at 0.2 MPa, and a universal primer (Monobond Plus; Ivoclar AG) was applied to the external surfaces of the Ti-base abutments, which was left to react for 60 seconds. The same primer was applied to the intaglio surfaces of the crowns, which were then randomly (Excel; Microsoft Corp) cemented to Ti-base abutments with an autopolymerizing dental luting composite resin (Multilink Hybrid Abutment H0; Ivoclar AG) (Fig. 2). After removing excess cement, a 24-N force was applied for 7 minutes by using a loading device to standardize cementation. After the cementation procedures had been completed, the screw access channel of each crown was sealed with Teflon tape (Teflon; Kirchhoff GmbH) and a light-polymerizing composite resin (Filtek Z250; 3M ESPE).

All specimens were digitized by using a 3D profilometer laser scanner with a triangular displacement sensor (LAS-20; SD Mechatronik) with a horizontal resolution of 0.04 mm[13] and an accuracy of 0.1% over the full scale. Plastic cylinders with the crown-implant complex were placed in fixed plastic molds to ensure standardized positioning during scans. All specimens were then stored in distilled water at 37 °C for 24 hours and then subjected to thermomechanical aging in distilled water under a 50-N load with 1.2 million cycles and 0.7-mm lateral sliding (5 °C to 55 °C, dwell time 30 seconds) by using a mastication simulator (Chewing Simulator CS-4.10; SD Mechatronik).[5,13] A Ø6-mm stainless steel sphere was used as the antagonist and aligned between the cusps. Then, all specimens were rescanned as specified previously. Postaging datasets, which were considered as target data, were superimposed over their respective reference preaging datasets by using the iterative closest point best-fit alignment of a metrology-grade 3D analysis software program (Geomagic Control X 2020.1; 3D Systems) to analyze the worn area (Fig. 3). After superimposition, worn areas on the occlusal surfaces were analyzed by

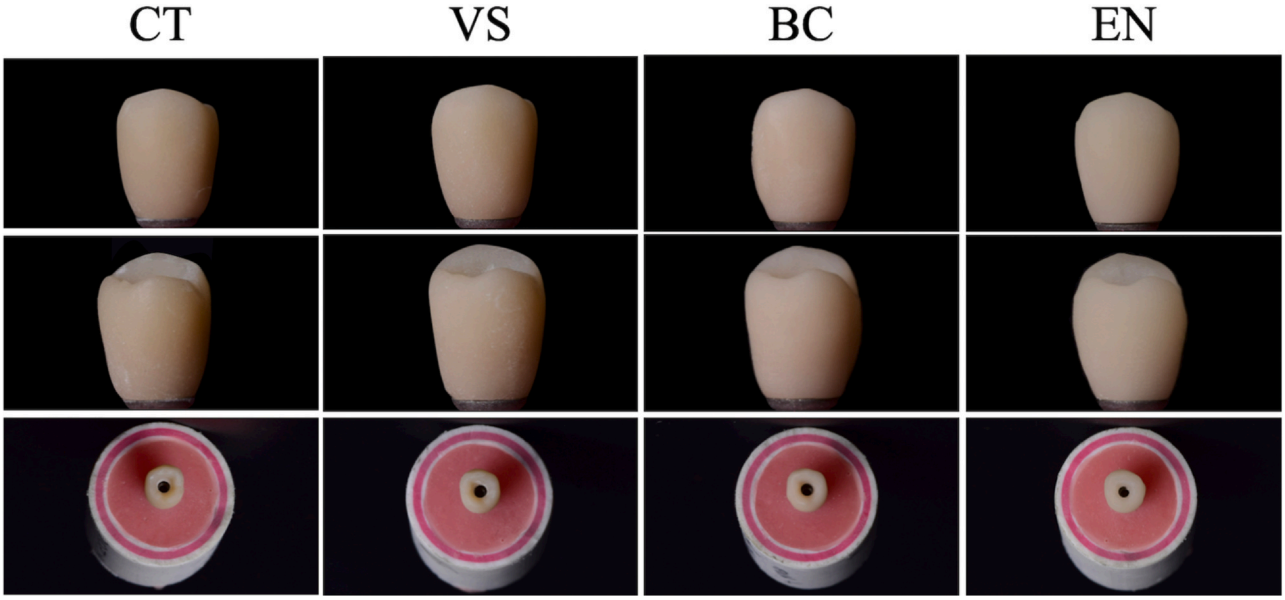


Figure 2. Additively and subtractively manufactured screw-retained, implant-supported crowns. BC, Brilliant Crios; CT, Crowntec; EN, Enamic; VS, VarseoSmile Crown Plus.

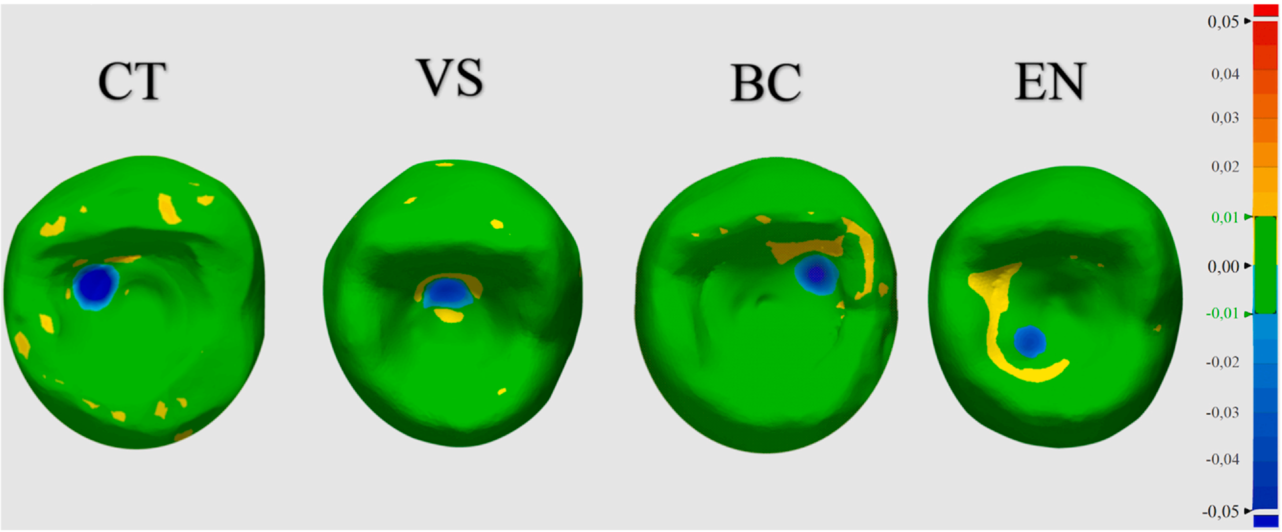


Figure 3. Color maps generated after superimposing postaging dataset over preaging dataset. BC, Brilliant Crios; CT, Crowntec; EN, Enamic; VS, VarseoSmile Crown Plus.

using the “3D Compare Tool” with maximum and minimum deviation values set at +50 µm and −50 µm and the tolerance range set at +10 µm and 10 µm.[23] Each worn area was manually cropped on both data sets and using the "measurement tool-volume inspection tool-enclosed volume" feature, the volume of the cropped area was automatically calculated for both datasets, and the absolute volume difference was determined by calculating the difference between these values (Fig. 4). After volume loss measurements, a plane that encompassed the worn area was generated, and the maximum depth of wear was defined as the highest distance between this plane and the worn area on the z-axis. A buccopalatal cross-section that equally divided the worn area was also generated to ensure that the selected point on the worn area was at the deepest point (Fig. 5).

A fracture load test was performed on a universal testing device (AGS-X; Shimadzu Corp). Force at a crosshead speed of 1 mm/min was applied with a Ø6-mm sphere, and the maximum fracture strength values were recorded. Even distribution of the force was maintained by placing a thin aluminum foil between the specimen and the antagonist during the test.[4] One specimen from each group was further analyzed with scanning electron microscopy (SEM) (EVO LS-10; Zeiss) under ×59 and ×100 magnifications at 25 kV.

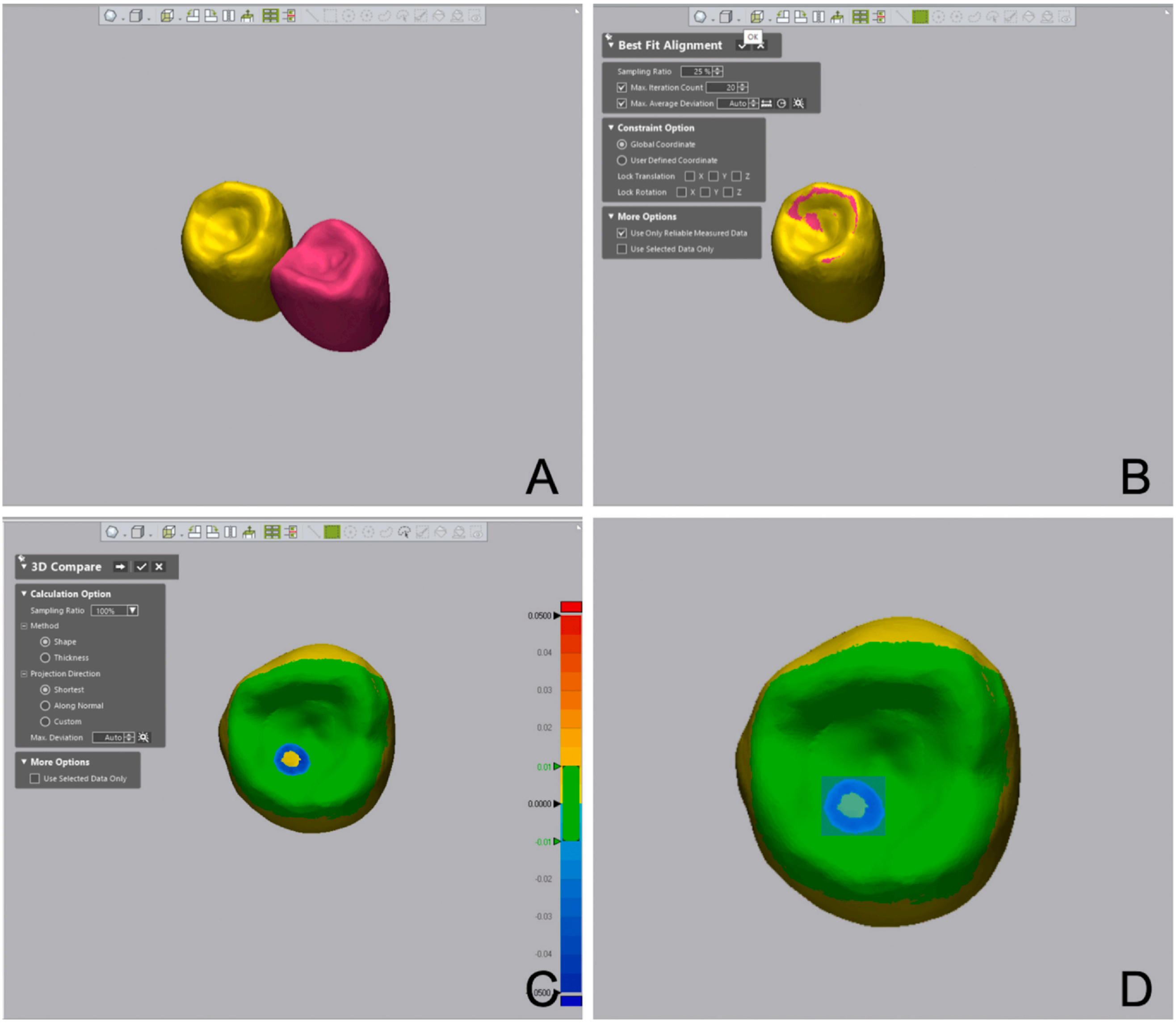
The normality of the data was evaluated by using Shapiro-Wilk tests. One-way analysis of variance followed by post hoc Tukey HSD tests were used to analyze fracture resistance and volume loss, whereas the Kruskal-Wallis and Dunn tests were used to analyze maximum wear depth. Weibull analysis was performed by using the maximum likelihood estimation method (Minitab Software V.17; Minitab), and chi-square tests were used to analyze Weibull moduli and characteristic strength values. The remaining statistical analyses were performed by using an analysis software program (IBM SPSS Statistics, v23; IBM Corp) ($\alpha=.05$).

RESULTS

None of the crowns failed during thermomechanical aging. Significant differences were observed among materials when volume loss at the wear area was considered ($P<.001$). CT and VS had similar volume loss ($P=.998$) that was significantly higher than that of the other materials ($P<.001$). In addition, the difference between BC and EN was not significant ($P=.374$) (Table 3). Material type had a significant effect on maximum wear depth ($P<.001$). BC and EN had similar values ($P=.999$), which were significantly lower than those of other materials ($P<.001$). The difference between VS and CT was not significant ($P=.991$) (Table 4).

Significant differences were observed among materials when fracture resistance was considered ($P<.001$). EN had the highest values ($P<.001$), whereas BC had higher values than CT ($P=.011$). VS had similar values to those of BC ($P=.615$) and CT ($P=.173$). Even though the Weibull moduli of tested materials were similar ($P=.199$), EN had the highest characteristic strength values ($P<.001$) (Table 5). Figure 6 shows the survival probability of the tested materials.

The SEM images showed the crack propagation around the screw access channels, indicating a stress-bearing area, regardless of the material tested. In addition, none of the cracks had a distinctive propagation, as



Best Fit Alignment

Sampling Ratio 25 %
☑ Max. Iteration Count 20
☑ Max. Average Deviation Auto

Constraint Option

● Global Coordinate
○ User Defined Coordinate
Lock Translation ☐ X ☐ Y ☐ Z
Lock Rotation ☐ X ☐ Y ☐ Z

More Options

☑ Use Only Reliable Measured Data
☐ Use Selected Data Only

3D Compare

Calculation Option

Sampling Ratio 100%
Method
● Shape
○ Thickness
Projection Direction
● Shortest
○ Along Normal
○ Custom
Max. Deviation Auto

More Options

☐ Use Selected Data Only

Figure 4. Superimposition of postscan data (*purple*) over prescan data (*yellow*). A, Postaging and preaging data before superimposition. B, Postaging and preaging data after superimposition by using best-fit alignment. C, Color map generated after superimposition. D, Manual selection of worn area on both datasets.

they were all in a vertical direction. CT and VS had lamellar structures, whereas EN and BC had horizontal lines at the junction of the screw access channel and the Ti-base abutment; these were considered to be associated with the manufacturing method of each material (Fig. 7).

DISCUSSION

Even though screw-retained, implant-supported crowns of the same manufacturing method had similar volume loss and maximum wear depth, CT and VS had higher volume loss and maximum wear depth than BC and EN. Therefore, the null hypotheses concerning volume loss and maximum wear depth were rejected.

The composition of a material may be related to its wear resistance.[28] The chemical compositions of CT and VS were similar; thus, they may be expected to have similar hardness and wear behavior.[15] Qualitative evaluation of the color maps and cross-sectional images of CT and VS revealed that the worn areas of these groups were somewhat similar to each other, being broader and deeper than those of BC and EN. Previous studies on the

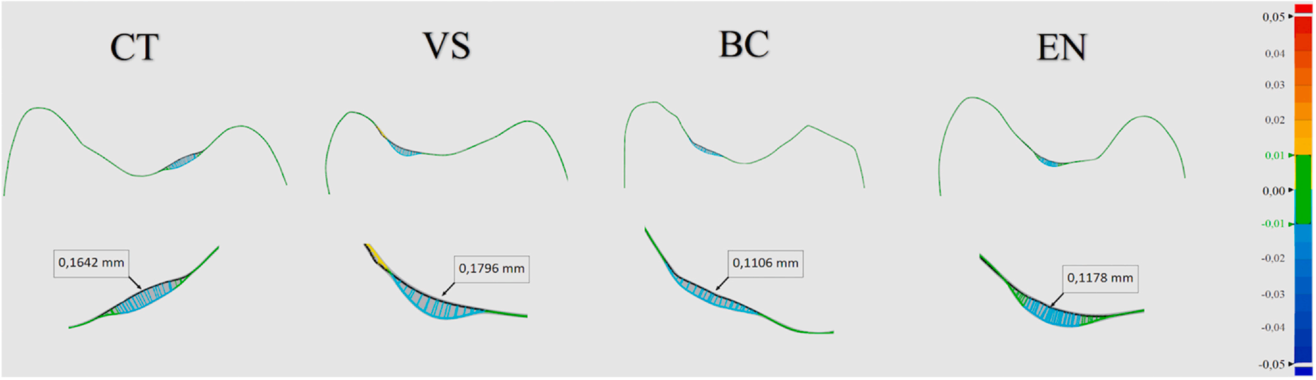


Figure 5. Representative image of worn area after superimposing postaging dataset over preaging dataset. BC, Brilliant Crios; CT, Crowntec; EN, Enamic; VS, VarseoSmile Crown Plus.

Table 3. Mean ± standard deviation and 95% CI volume loss values of materials

Material	Volume Loss (mm^3)	95% CI (mm^3)
CT	0.43 ± 0.01^{b}	0.42-0.44
VS	0.43 ± 0.02^{b}	0.42-0.44
BC	0.37 ± 0.01^{a}	0.36-0.37
EN	0.36 ± 0.01^{a}	0.35-0.36

BC, Brilliant Crios; CI, confidence interval; CT, Crowntec; EN, Enamic; VS, VarseoSmile Crown Plus.

Different superscript lowercase letters indicate significant differences among materials (*P* < .05).

Table 4. Descriptive statistics of maximum wear depth (mm) values of materials

Material	Median (Min-Max)	Mean ± Standard Deviation (95% Confidence Interval)
CT	0.16^{b} (.15-0.17)	0.16 ± 0 (0.16-0.16)
VS	0.17^{b} (0.14-0.19)	0.16 ± 0.02 (0.15-0.17)
BC	0.12^{a} (0.10-0.12)	0.11 ± 0.01 (0.11-0.12)
EN	0.11^{a} (0.09-0.13)	0.11 ± 0.01 (0.10-0.12)

BC, Brilliant Crios; CT, Crowntec; EN, Enamic; VS, VarseoSmile Crown Plus.

Different superscript lowercase letters indicate significant differences among materials (*P* < .05).

Table 5. Mean ± standard deviation (95% CI) fracture resistance, Weibull modulus, and characteristic strength values of materials

Material	Fracture Resistance (N)	Weibull Modulus	Characteristic Strength (N)
CT	536 ± 58^{a} (494–578)	11.4^{a} (6.9-18.9)	561^{a} (530-594)
VS	587 ± 49^{ab} (551–622)	12.4^{a} (8-19.4)	609^{a} (577-642)
BC	616 ± 56^{b} (576–656)	15^{a} (9.1-24.7)	639^{a} (612-667)
EN	803 ± 51^{c} (767–840)	17.2^{a} (10.9-27.3)	827^{b} (796-859)

BC, Brilliant Crios; CI, confidence interval; CT, Crowntec; EN, Enamic; VS, VarseoSmile Crown Plus.

Different superscript lowercase letters indicate significant differences among materials (*P* < .05).

hardness of these materials also reported mean Vickers hardness values within the same range.[14,21] However, the authors are unaware of a study on the direct comparison of the hardness of CT and VS, and manufacturers of these resins disclosed internal test results that were performed using different hardness tests.[32,33] Rosentritt et al[16] investigated the wear behavior of VS and reported similar mean and maximum wear depth when compared with other additively and subtractively manufactured resin-based materials that were not tested in the present study. However, the authors are unaware of a study that compared the wear behavior of CT and VS. Therefore, a direct comparison with previous studies was not possible. BC and EN had similar volume loss and maximum wear depth, consistent with a previous study,[34] that were significantly lower than those of CT and VS. The reduced wear may have been associated with the higher ceramic content[27] along with the fact that BC and EN were prepolymerized under standardized conditions, which may have led to a higher degree of conversion and more favorable physical properties.[16] Another reason for the higher volume loss and maximum wear depth of VS and CT might be the detrimental effect of water sorption, as water absorption into materials with high polymeric content might lead to lower resistance to wear because of softening and hydrolysis of the silane agent.[34] However, this hypothesis

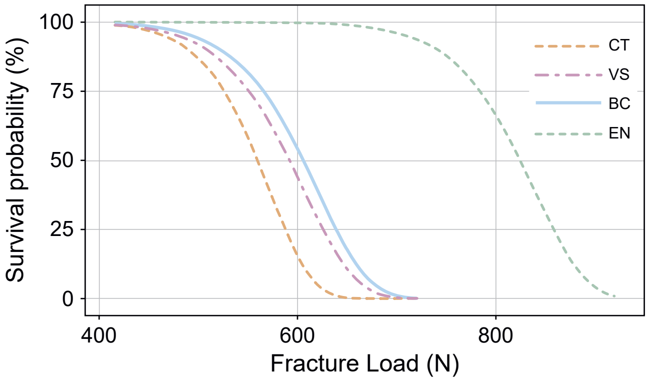


Figure 6. Survival probability curves of tested materials. BC, Brilliant Crios; CT, Crowntec; EN, Enamic; VS, VarseoSmile Crown Plus.

needs to be supported with studies on the degradation of VS and CT when subjected to thermomechanical aging, as a recent study reported that the hardness of CT did not change after thermal aging.[21] Nevertheless, all materials had a maximum wear depth that was higher than the reported annual enamel wear at the premolar region (17.3 μm),[29] which may be related to the fact that the specimens were not polished or glazed after fabrication.

The null hypothesis concerning fracture resistance was rejected, as CT had lower fracture resistance values than those of subtractively manufactured materials ($P \leq .011$), whereas VS had lower fracture resistance values than EN ($P < .001$). The standardized polymerization process of EN, along with its ceramic filler content, which was the highest among the tested materials, may be related to its significantly high fracture resistance values. The results of the Weibull analysis also support this hypothesis, as EN had the highest characteristic strength. However, all materials had mean fracture resistance values that were either within or higher than the previously reported range for the physiological masticatory forces of the premolar region (424-583 N).[35] Nevertheless, masticatory forces may be higher for patients with implant-supported restorations because of lack of proprioception and also in patients with bruxism.[7] Even though the thermomechanical aging process used in the present study simulated approximately 5 years intraorally,[5] in vivo studies are needed to confirm the applicability of tested additively manufactured screw-retained, implant-supported crowns without any fractures.

To the authors' knowledge, only 1 study focused on the fracture resistance of additively manufactured implant-supported crowns, and that stated that CT, BC, and EN had similar fracture resistance when no aging was performed.[25] Studies of the fracture resistance of VS are also sparse, and the only study on this topic reported that VS had similar fracture resistance to that of other resin-based materials after thermomechanical aging when fabricated as a molar-shaped, tooth-supported crown.[16] Both studies[16,25] also reported higher fracture resistance values than those of the present study, which may be associated with the absence of aging[25] and a restoration design that did not include a screw access channel.[16,25] BC and EN have also been compared with additively manufactured definitive composite resins in other previous studies, and contradicting results have been reported.[10,17,18] Corbani et al[17] reported significantly higher fracture resistance values for an additively manufactured nanocomposite resin when compared with BC. However, Zimmermann et al[10] reported that the additively manufactured composite resin tested in their study had similar fracture resistance to that of BC and higher than that of EN. In addition, BC was shown to have significantly higher fracture resistance than this composite resin[10] when fabricated as a 3-unit fixed partial denture.[18]

The present study compared the mechanical properties of screw-retained, implant-supported crowns fabricated by using additively and subtractively manufactured resins; thus, no polishing or glazing was performed. This is of particular importance as the surfaces of CT and VS screw-retained, implant-supported crowns were airborne-particle abraded, consistent with manufacturer recommendations. This process might have increased their roughness and affected crack initiation and propagation. Considering that surface treatments change the surface topography, the results of the present study should be substantiated with future studies on how tested parameters are affected after different surface finishing procedures.

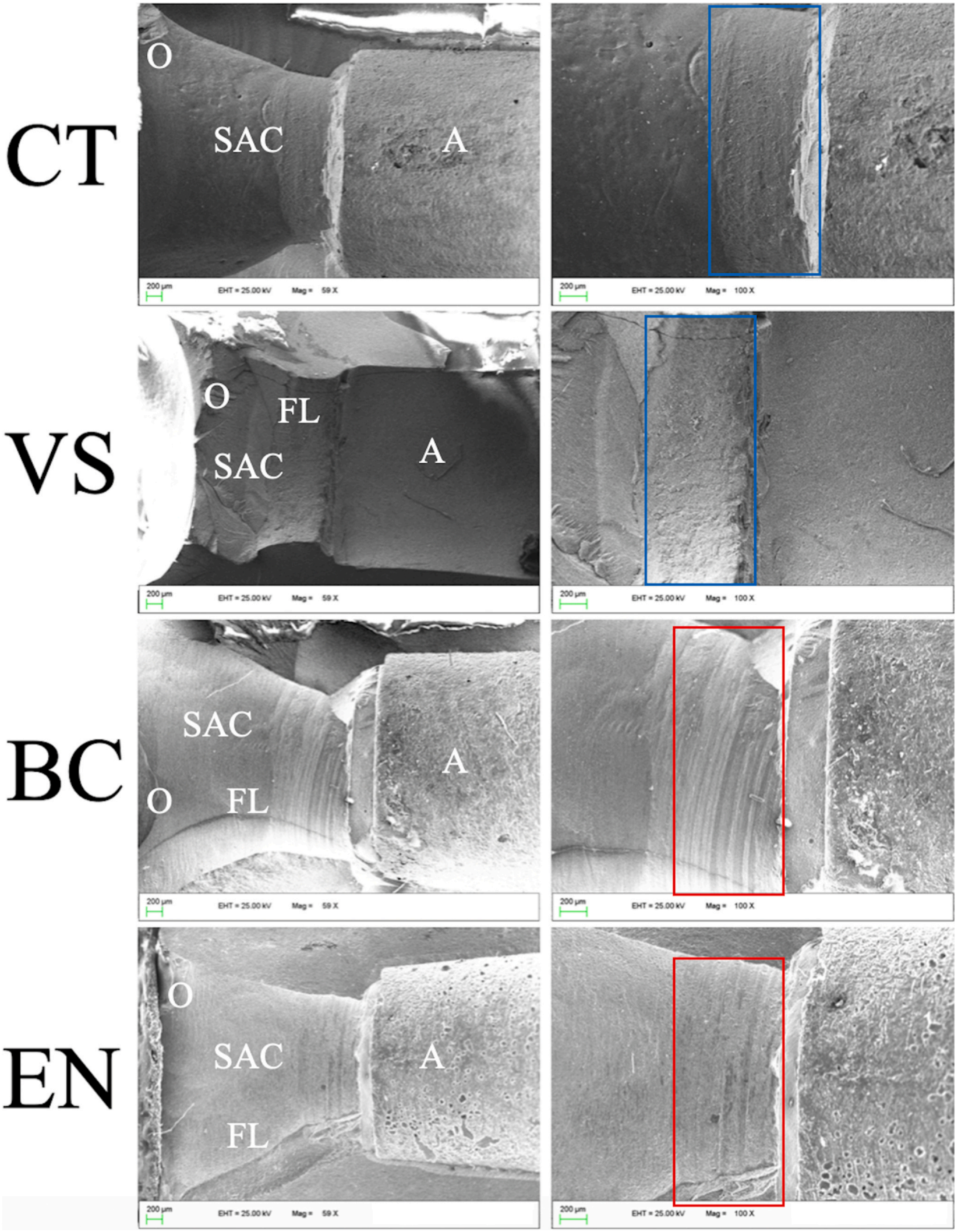


Figure 7. Representative scanning electron microscopy images of fractured specimens from each group. Left: original magnification ×59. Right: original magnification ×100. *Blue rectangles* indicate lamellar structures. *Red rectangles* indicate horizontal lines. A, Abutment; BC, Brilliant Crios; CT, Crowntec; EN, Enamic; O, Origin of fracture; SAC, Screw access channel; VS, VarseoSmile Crown Plus.

The screw access channels were not visually assessed before testing to ensure that they were free from defects, and, given that different materials fabricated by using different manufacturing technologies were tested in the present study, the fabrication trueness and internal surface topography of the screw access channels may have affected the fracture resistance values. In addition, only one 3D printer and one milling unit were used to fabricate tested screw-retained, implant-supported crowns. Clinical conditions could have been better reflected if artificial saliva or enamel antagonists had been used during thermomechanical aging. In addition, different antagonists may affect wear characteristics,[26] and the wear of the antagonist should also be evaluated.

Best fit alignment based on the iterative closest point algorithm was used in the present study to avoid operator-related errors. However, landmark-based alignment or reference alignment may lead to different results.[36] Fracture resistance of implant-supported restorations is affected by other parameters, which should also be investigated.[7,10,11,17] Future studies on screw-retained, implant-supported crowns fabricated by using CT and VS should investigate how different printing parameters affect the mechanical properties of prostheses, along with how screw stability is affected when cyclic loading is applied, to corroborate the results of the present study.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. Additively manufactured screw-retained, implant-supported crowns presented higher volume loss and maximum wear depth compared with subtractively manufactured screw-retained, implant-supported crowns. However, the differences between materials within each manufacturing method were not significant.
2. Polymer-infiltrated ceramic network, which has the highest ratio of ceramic fillers, had the highest fracture resistance values, whereas 1 of the additively manufactured resins, VS product, presented similar values to that of the subtractively manufactured reinforced composite resin.
3. All materials had fracture resistance values within the range of or higher than the physiological masticatory forces reported for the premolar region.

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