THE JOURNAL OF PROSTHETIC DENTISTRY

RESEARCH AND EDUCATION

# Fracture strength of additively manufactured one-piece endodontic crowns in resins for definitive use: Effect of material type, margin configuration, and pulp chamber depth

Mustafa Borga Donmez, DDS, PhD,[a] Ece Ersöz, DDS,[b] Gülce Çakmak, DDS, PhD,[c] Almira Ada Diken Türksayar, DDS,[d] Pinar Altinci, DDS, PhD,[e] and Burak Yilmaz, DDS, PhD[f]

## ABSTRACT

**Statement of problem.** Additive manufacturing enables the fabrication of definitive resin 1-piece endodontic crowns, but information on how resin type and preparation design affect their fracture strength is limited.

**Purpose.** This in vitro study aimed to evaluate the effects of material type, margin configuration, and pulp chamber depth on the fracture strength of additively manufactured (AM) 1-piece endodontic crowns compared with those subtractively manufactured (SM).

**Material and methods.** One-piece endodontic crowns were designed by using the scans of 4 mandibular first molar typodonts prepared with either butt joint or 1-mm shoulder margins and pulp chamber depths of 2 mm or 4 mm. These designs were used to fabricate specimens either additively (Tera Harz TC80DP [GR], FREEPRINT Crown [FP], Crowntec [CT]) or subtractively (Tetric CAD [TC]) (n=7). Scans of the prepared typodonts were used to additively manufacture resin dies, and each specimen was cemented to its corresponding die using a dual-polymerizing resin cement. After cementation, all specimens were subjected to cyclic loading (1.2 million cycles, 49 N) before the load-to-fracture test. Fracture load data were analyzed with a generalized linear model and Bonferroni-corrected post hoc tests ($\alpha$=.05).

**Results.** All specimens survived cyclic loading and were subjected to the load-to-fracture test. The interaction among all main factors affected measured values ($P$=.028). CT led to the highest fracture load among the specimens with butt joint margins and 4-mm depth, while TC led to the highest values among those with shoulder margins, regardless of the pulp chamber depth ($P\leq$.002). Butt joint margins resulted in higher values for GR and CT specimens with 4-mm depth, while shoulder margins led to higher values for FP and CT specimens with 2-mm depth, as well as for TC specimens ($P\leq$.020). A depth of 4 mm resulted in higher values for all specimens with butt joint margins and for TC specimens with shoulder margins, whereas 2-mm depth led to higher values for FP specimens with shoulder margins ($P\leq$.016).

**Conclusions.** The fracture strength of the tested 1-piece endodontic crowns was affected by the material type, margin configuration, and pulp chamber depth. However, all specimens had acceptable mean fracture load values according to the previously reported masticatory forces of the molar region. (J Prosthet Dent 2026;135:806.e1-e8)

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

[a]Associate Professor, Department of Prosthodontics, Faculty of Dentistry, Biruni University, Istanbul, Turkey; and External Researcher, Department of Reconstructive Dentistry and Gerodontology, School of Dental Medicine, University of Bern, Bern, Switzerland.
[b]PhD Student, Department of Prosthodontics, Faculty of Dentistry, Lokman Hekim University, Ankara, Turkey.
[c]Senior Research Associate, Department of Reconstructive Dentistry and Gerodontology, School of Dental Medicine, University of Bern, Switzerland; Head of the Digital Dental Technology Laboratory, Department of Prosthodontics, Geriatric Dentistry and Craniomandibular Disorders, Charité Universitätsmedizin Berlin, Corporate Member of Freie Universität Berlin and Humboldt-Universität zu Berlin, Berlin, Germany; and External Researcher, Department of Prosthodontics, Faculty of Dentistry, Biruni University, Istanbul, Turkey.
[d]Associate Professor, Department of Prosthodontics, Faculty of Dentistry, Biruni University, Istanbul, Turkey.
[e]Clinical Practitioner, Tikkurila Healthcare Center Dental Clinic, Vantaa and Kerava Wellbeing County, Vantaa, Finland.
[f]Professor, Department of Reconstructive Dentistry and Gerodontology, School of Dental Medicine, University of Bern, Bern, Switzerland; Professor, Department of Restorative, Preventive and Pediatric Dentistry, School of Dental Medicine, University of Bern, Bern, Switzerland; Adjunct Professor, Division of Restorative and Prosthetic Dentistry, The Ohio State University, Columbus, OH, USA; and Adjunct Professor, Department of Prosthodontics, Faculty of Dentistry, Ankara University, Ankara, Turkey.

## Clinical Implications

The tested AM resins intended for definitive use may be reliable alternatives to SM ceramic-reinforced resin composite for molar 1-piece endodontic crowns when the tested preparation and print parameters are used. For 1-piece endodontic crowns made from the tested materials, deeper pulp chamber design may be preferred, particularly with butt joint margin preparations, for higher fracture load.

Endodontically treated teeth often require complex restorative approaches because their structural integrity is largely compromised by caries, access cavity design, and dentin removal during endodontic therapy.[1] Conventionally, severely damaged posterior teeth have been restored with post-and-core systems and crowns to improve strength, prevent contamination, and reestablish function.[2,3] However, the placement of post-and-core restorations might reduce fracture strength because of the required additional dentin removal while simultaneously increasing the possibility of root perforation.[4,5] When sufficient tooth structure and bonding area are present, posts can be avoided, and 1-piece endodontic crowns can provide a conservative alternative by combining the core and crown into a monoblock that relies on pulp chamber support and adhesive retention.[6–9] One-piece endodontic crowns conservatively restore coronal structure, seal root canal access, and allow easier reintervention, offering a functional and esthetic restorative option.[10] Ceramics offer esthetic and mechanical advantages for 1-piece endodontic crowns but may not mimic natural tooth biomechanics. Resin-based materials can also be used, as they provide better stress distribution on remaining tooth structure and have promising mechanical properties[11] with fracture strength similar to or higher than ceramic 1-piece endodontic crowns.[12]

Recent studies have indicated that 1-piece endodontic crowns offer biomechanical strength comparable with or exceeding that of conventional restorations in damaged anterior and posterior teeth, with favorable long-term outcomes[13–15]; this is further enhanced by advances in computer-aided design and computer-aided manufacturing (CAD-CAM) technologies.[1] One-piece endodontic crowns can be fabricated from CAD files either subtractively, by milling prefabricated blocks, or additively, by building layer-by-layer, allowing complex and multilayer designs.[16] Additive manufacturing is often more cost-efficient and generates less material waste than subtractive methods.[17] The development of resins suitable for definitive restorations has further expanded its use in dentistry.[18–22]

While several recent studies have investigated additively manufactured (AM) 1-piece endodontic crowns,[1,2,7,8,16,17,23] knowledge of their fracture strength is limited.[1,2,17] Given that their fracture strength depends on material type, margin configuration, and pulpal chamber extension,[1,3–6,17,24–27] studies examining how preparation design (margin configuration and pulp chamber depth) affects the fracture strength of AM 1-piece endodontic crowns can help clinicians make informed restorative decisions. While 1-piece endodontic crowns are not completely conservative, they preserve more tooth structure than crowns,[25] making it important to evaluate whether maintaining intact dental tissues or increasing the restoration's dimensions offers better mechanical outcomes, particularly with different AM resins intended for definitive use in clinical practice. Therefore, the present study aimed to compare the fracture strength of AM 1-piece endodontic crowns with different preparation designs and fabricated using resins intended for definitive use with subtractively manufactured (SM) 1-piece endodontic crowns. The null hypothesis was that the material type, margin configuration, and pulp chamber depth would not affect the fracture strength of the tested 1-piece endodontic crowns.

## MATERIAL AND METHODS

Figure 1 shows the overview of this study. Four identical mandibular left first molar typodont teeth (ANA-4; frasaco GmbH) were modified by sectioning them 2 mm below the occlusal surface using a low-speed saw under water irrigation (IsoMet Low Speed Saw; Buehler). This step ensured standardized surfaces representative of molars with extensive structural loss. Each specimen was prepared for a 1-piece endodontic crown featuring either a butt joint or a 1-mm-wide shoulder margin, along with a pulp chamber depth of 2 mm or 4 mm. The pulp chamber was shaped to be 3 mm from the distal wall and 2 mm within the mesial wall, with an internal axial wall taper of 6 degrees.[16] Digital scans of each prepared molar were made with an intraoral scanner (Primescan SW5.2; Dentsply Sirona) in a controlled environment with a temperature of 20 °C and 45% relative humidity.[28] The resulting standard tessellation language (STL) files were imported into a dental CAD software program (DentalCAD 3.0 Galway; exocad GmbH), where 4 separate 1-piece endodontic crowns were designed with a cement space of 50 μm.[16] The finalized design files were used to fabricate a total of 112 specimens by either additive or subtractive manufacturing using materials approved for definitive restorations: a urethane acrylate-based resin without any fillers (Tera Harz TC-80DP; Graphy) (GR), 2 ceramic-filled hybrid

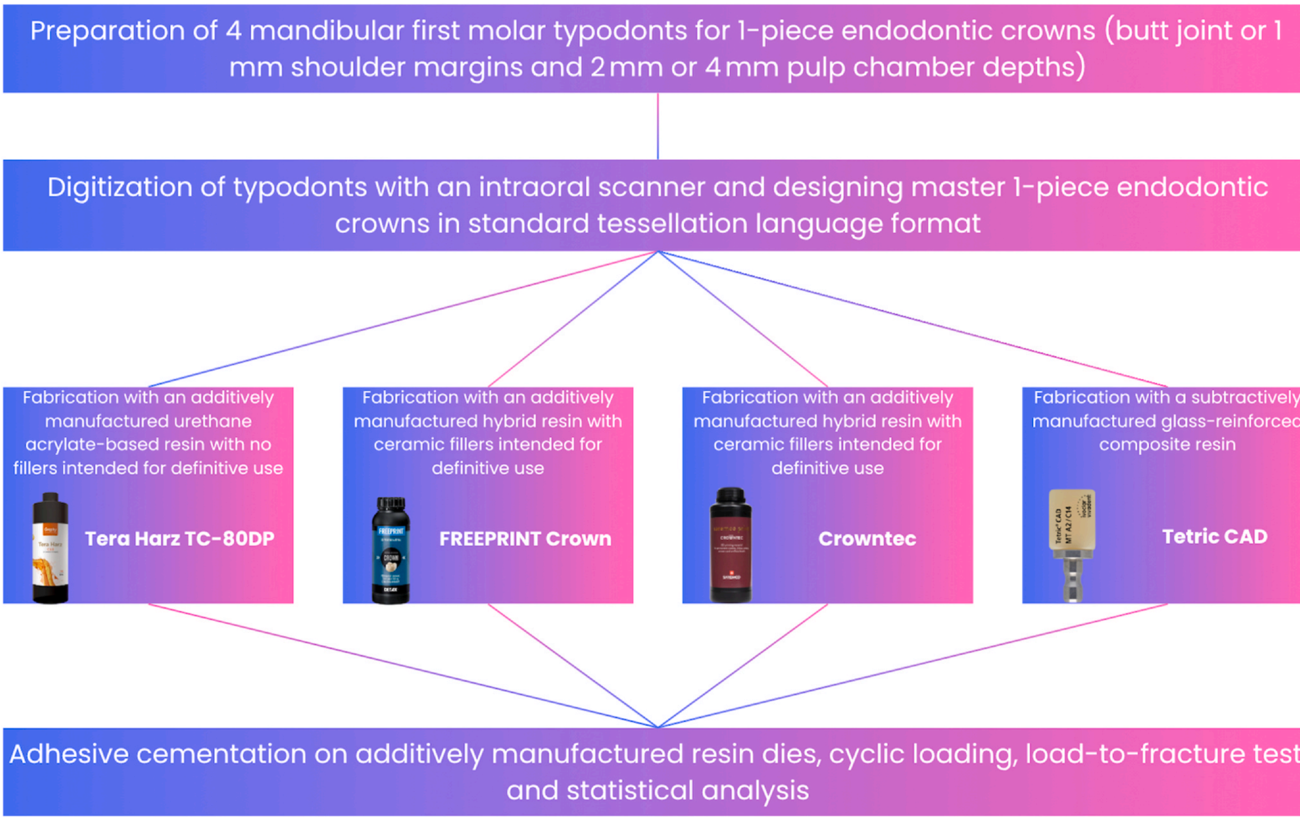


**Figure 1.** Overview of study design.

resins (FREEPRINT Crown; Detax and Crowntec; Saremco Dental AG) (CT and FP), and a glass-reinforced composite resin for subtractive milling (Tetric CAD; Ivoclar AG) (TC) (n=7). Detailed material specifications are provided in Table 1. The sample size was determined via priori power analysis for %95 CI (1-α), 95% power (1-β), and effect size of f=0.904, based on the mean and standard deviation values from a previous study.[23]

GR, FP, and CT specimens were AM using a digital light processing 3D printer (MAX UV; Asiga). Each design file was imported into the printer manufacturer's proprietary nesting software program (Composer v2.0; Asiga) in separate nesting jobs and oriented with the occlusal surface facing the build platform. Automatic support structures were generated, with any supports contacting the intaglio surface or margins removed to avoid surface interference. For standardization, each design was duplicated until 7 specimens were positioned per job and printed with a layer thickness of 50 μm. After printing, CT specimens were cleaned with 96% ethanol using ethanol-soaked cloths; FP specimens were rinsed in ≥98% isopropyl alcohol for 3 minutes, followed by a

**Table 1.** Detailed information of tested materials

| Material | Type | Chemical Composition | Filler Ratio | Abbreviation |
|---|---|---|---|---|
| Tera Harz TC-80DP | Additively manufactured urethane acrylate-based resin with no fillers intended for definitive use | Urethane acrylate oligomer, bisphenol A ethoxylate dimethacrylate, 2-hydroxyethyl methacrylate, diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide, and additives | - | GR |
| FREEPRINT Crown | Additively manufactured hybrid resin with ceramic fillers intended for definitive use | Alkoxylated phenol derivative, methacrylate terminated; 7,7,9(or 7,9,9)-trimethyl-4,13-dioxo-3,14-dioxa-5,12-diazahexadecane-1,16-diyl bismethacrylate; 1,6-hexanediol dimethacrylate; Hydroxy propyl methacrylate; diphenyl(2,4,6-trimethylbenzoyl)phosphine oxide; phenyl bis(2,4,6-trimethylbenzoyl)-phosphine oxide | 20-40 wt% ceramic fillers | FP |
| Crowntec | Additively manufactured hybrid resin with ceramic fillers intended for definitive use | Esterification products of 4.40- isopropylphenol, ethoxylated and 2- methylprop-2enoic acid, silanized dental glass, pyrogenic silica, initiators | 30-50 wt% ceramic fillers | CT |
| Tetric CAD | Subtractively manufactured glass-reinforced composite resin | Barium glass filler, silicon dioxide, dimethacrylates, additives and pigments | 71.1 wt% ceramic fillers | TC |

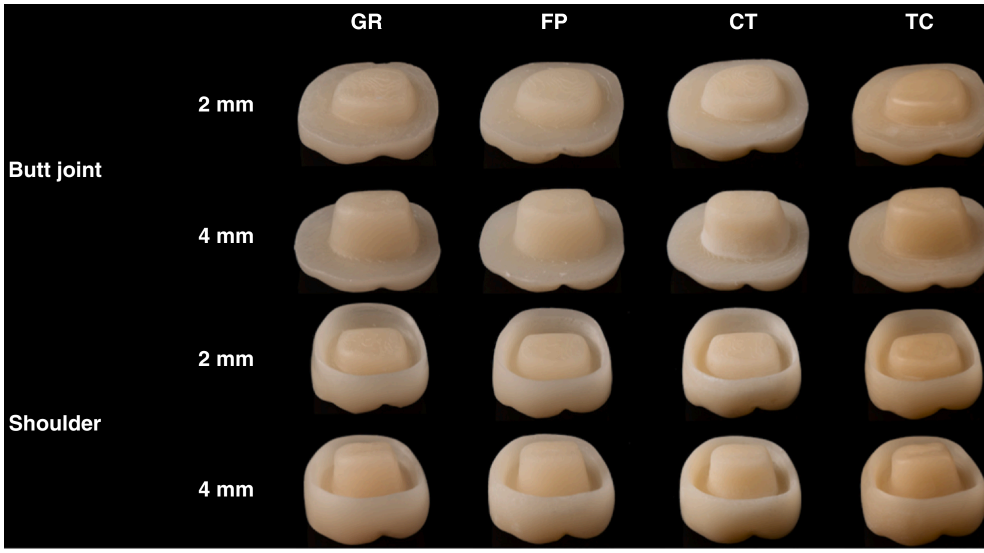


**Figure 2.** Representative images of tested specimens within each subgroup. CT, Crowntec; FP, FREEPRINT Crown; GR, Tera Harz TC-80DP; TC, Tetric CAD.

second rinse in fresh isopropyl alcohol for 2 minutes; GR specimens were ultrasonically cleaned in 96% ethanol for 45 seconds, followed by manual cleaning with ethanol-soaked cloths. All specimens were then air dried and postpolymerized using a xenon flash polymerization unit (Otoflash G171; NK-Optik GmbH) under a nitrogen oxide atmosphere with 4000 flashes (2×2000 flashes) in accordance with manufacturer recommendations and previous studies.[20,29–33] TC specimens were manufactured using a 5-axis milling unit (PrograMill 7; Ivoclar AG) with wet milling performed under the high-finish strategy. The support structures of all specimens were removed, and the external surfaces were smoothed under ×3.5 magnification (EyeMag Pro; Carl Zeiss) with finishing burs designed for hybrid ceramics (Nano Ceramic Chairside Polishing; Jota AG) without altering the intaglio surface (Fig. 2). No further polishing or glazing was performed on any of the specimens, which were manufactured by 1 experienced prosthodontist (P.A.).

The same 3D printer was also used to fabricate resin abutments corresponding to each specimen. Scan files of the prepared typodont molars were imported into the same nesting software program and oriented with their base parallel to the build platform. After automatic support generation, the abutments were printed using the manufacturer's proprietary dental model resin (DentaMODEL; Asiga) at a layer thickness of 100 µm,[34] resulting in a total of 112 abutments across tested preparation designs (n=28). After printing, abutments were ultrasonically cleaned in ≥98% isopropyl alcohol for 10 minutes (5-minute prewash and 5-minute postwash), air dried, and postpolymerized in the same manner as the AM specimens. The abutments were then randomly assigned to their corresponding specimens using a software program (Excel; Microsoft Corp).

Prior to cementation, the intaglio surfaces of all specimens were airborne-particle abraded with 50-µm aluminum oxide (Cobra; Renfert) at 0.2 MPa from 10 mm for 10 seconds, followed by steam cleaning from 10 cm for 5 seconds and drying with oil-free compressed air.[35] A universal adhesive (Adhese Universal; Ivoclar AG) was applied to the abutments for 20 seconds, and then gently airdried for 5 seconds before being light-polymerized for 5 seconds using the high-power mode of a light emitting diode (LED) polymerization unit (Bluephase; Ivoclar AG).[21] A dual-polymerizing resin cement (Variolink Esthetic DC; Ivoclar AG) was applied to the treated surfaces of the specimens with the manufacturer's syringes before placing them on their respective abutments. A brass rod was used to apply a constant force of 2 N to stabilize the specimens on their abutments throughout the cementation process.[21,35] The same LED polymerization unit was used to polymerize the resin cement for 3 seconds from each side of the specimens, after which excess cement was removed with a microbrush (Micro Stix; Microbrush International). The specimens were subsequently light polymerized for an additional 40 seconds (10 seconds on each side) and remained under the brass holder until 10 minutes had passed from the start of resin cement mixing.[35] After cementation, all specimens were stored in distilled water at 37 °C for 24 hours before cyclic loading.

Each specimen-abutment complex was mounted on a custom-built mastication simulator[35] and subjected to cyclic loading at 1.7 Hz for 1.2 million cycles under a 49-N load, simulating approximately 5 years of functional use.[36,37] Throughout the loading process, specimens

**Table 2.** Results of generalized linear model analysis

| | *P* |
|---|---|
| Material type | <.001 |
| Margin configuration | <.001 |
| Pulp chamber depth | <.001 |
| Material type × Margin configuration | <.001 |
| Material type × Pulp chamber depth | .013 |
| Margin configuration × Pulp chamber depth | <.001 |
| Material type × Margin configuration × Pulp chamber depth | .028 |

were immersed in distilled water,[38] and the force was applied using Ø12-mm polyoxymethylene spheres (Delrin; Dupont).[39] Polyoxymethylene was used to ensure uniform force distribution and reduce the risk of contact-induced fractures.[35] After cyclic loading, fracture testing was conducted using a universal testing machine (Instron 5942; Instron Corp) with a Ø12-mm stainless steel sphere applied at a crosshead speed of 1 mm/minute. The maximum load at fracture (N) was recorded for each specimen.

The normality of the data was confirmed with the Shapiro-Wilk test. Therefore, a generalized linear model analysis with material type, margin configuration, and pulp chamber depth was used to evaluate the fracture load values of the tested specimens, and every possible interaction among the main factors was included in the analysis. Pairwise comparisons were performed with Bonferroni-corrected post hoc tests. A statistical analysis software program (IBM SPSS Statistics, v26; IBM Corp) was used for the analysis ($\alpha$=.05).

## RESULTS

All specimens survived cyclic loading and were subjected to the load-to-fracture test. The results of the generalized linear model analysis revealed that the main factors ($P$<.001), every possible 2-way interaction ($P \leq .013$), and the 3-way interaction ($P$=.028) affected the fracture strength of the tested specimens (Table 2).

Table 3 shows the descriptive statistics of the measured fracture load values for each subgroup. Among the specimens with butt joint margins and 2-mm depth, CT had higher values than GR ($P$=.027), while among those with butt joint margins and 4-mm depth, CT had the highest values ($P \leq .001$). Among the specimens with shoulder margins and 2-mm depth, GR had the lowest and TC had the highest values ($P \leq .002$). Among the specimens with shoulder margins and 4-mm depth, TC had the highest values, followed by CT ($P$<.001). In the GR and CT specimens with 4-mm depth, butt joint margins led to higher values ($P$<.001). In FP, CT, and TC specimens with 2-mm depth and TC specimens with 4-mm depth, shoulder margins led to higher values ($P \leq .020$). Regardless of the material, 4-mm depth led to higher values when butt joint margins were used ($P \leq .013$). The 2-mm depth led to higher values for FP specimens with shoulder margins ($P$=.016), whereas the 4-mm depth led to higher values for TC specimens with shoulder margins ($P$=.013). Figure 3 illustrates the boxplot graph of measured values.

## DISCUSSION

The fracture strength of the tested 1-piece endodontic crowns were significantly affected by the material type, margin configuration, and pulp chamber depth, along with every interaction among these factors. Therefore, the null hypothesis that the material type, margin configuration, and pulp chamber depth would not affect the fracture strength of the tested 1-piece endodontic crowns was rejected. However, the statistically significant differences observed in this study may not be clinically meaningful, as a previous review reported molar region masticatory forces ranging from 306 N to 878 N under unilateral loading and from 491 N to 1110 N under bilateral loading.[40] Fracture loads in this study ranged from 901 N (GR crowns, shoulder margins, 4-mm pulp chamber) to 2052 N (TC crowns, shoulder margins, 4 mm), meeting or exceeding reported masticatory forces,[40] All specimens survived cyclic loading simulating approximately 5 years of function,[36,37] suggesting that the tested 1-piece endodontic crowns were likely suitable for clinical use with comparable mechanical durability.

Although significant factor interactions complicate attributing fracture strength solely to materials or designs, general trends allow some interpretation, as certain subgroups showed higher values despite

**Table 3.** Mean fracture load values and standard deviations for all subgroups (N). CT, Crowntec; FP, FREEPRINT Crown; GR, Tera Harz TC-80DP; TC, Tetric CAD

| | | Material | | | |
|---|---|---|---|---|---|
| **Margin Configuration** | **Pulp Chamber Depth** | **GR** | **FP** | **CT** | **TC** |
| Butt joint | 2 mm | 922 ±84[a] | 970 ±221[ab] | 1169 ±218[bcd] | 1119 ±124[abc] |
| | 4 mm | 1366 ±202[def] | 1250 ±241[cde] | 1775 ±233[g] | 1398 ±302[ef] |
| Shoulder | 2 mm | 1027 ±287[ab] | 1367 ±187[def] | 1429 ±280[ef] | 1774 ±170[g] |
| | 4 mm | 901 ±76[a] | 1097 ±229[abc] | 1513 ±280[f] | 2052 ±299[h] |

Different superscript lowercase letters indicate significant differences among subgroups ($P$<.05)

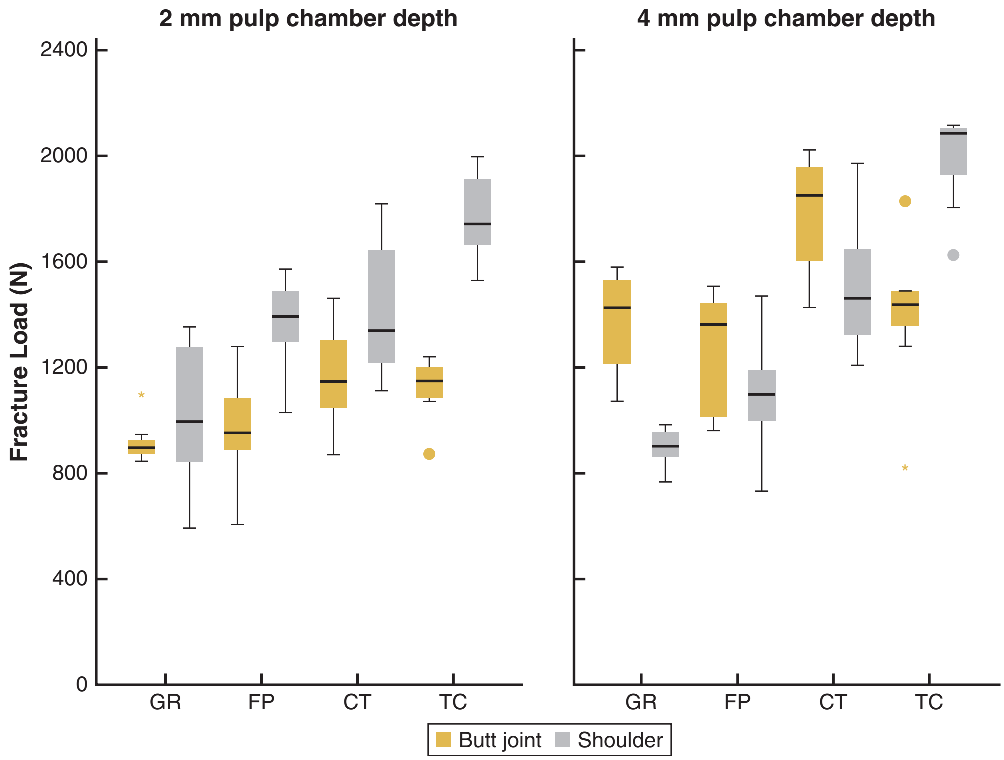


**Figure 3.** Box-plot graphs of measured fracture load values. CT, Crowntec; FP, FREEPRINT Crown; GR, Tera Harz TC-80DP; TC, Tetric CAD.

nonsignificant differences. Among the AM specimens, CT led to fracture load values that were statistically similar to or higher than those of other materials, regardless of margin configuration or pulp chamber depth. Given that all AM specimens were postprocessed according to the respective manufacturers' instructions and postpolymerized using the same unit and parameters, the observed differences may be attributed to variations in chemical composition and filler content among the tested resins, particularly since CT has the highest filler content. The FP resin exhibited fracture load values comparable with or higher than the GR resin, supporting this interpretation. These results align with those of previous studies on the mechanical properties of reinforced resins in dental additive manufacturing.[41–43] TC specimens had the highest fracture strength when shoulder margins were used and showed fracture load values that were similar to or higher than those of AM specimens when butt joint margins were used. In addition to the high ceramic filler content of TC, these findings may also be attributed to the manufacturing process, as these specimens were fabricated from prefabricated blocks that potentially have a higher degree of conversion than the tested AM resins because they were produced under standardized conditions with high temperature and pressure.[16,20,35,36] While no clear trend was observed for margin configuration, deeper pulp chamber preparations mostly resulted in higher fracture strength, which was significant for specimens with butt joint margins. This finding may be attributed to the increased contact area provided by greater pulp chamber depth preparation, which could enhance the stability and retention of the tested specimens.[10]

The authors are aware of only 3 studies that assessed the fracture strength of AM 1-piece endodontic crowns.[1,2,17] One study compared an AM resin for definitive use with SM composite and PEEK reinforced with ceramic fillers, reporting significantly lower fracture strength for AM premolar crowns with butt-joint margins and 2-mm pulp chambers.[2] Abuabboud et al[1] reported no effect of pulp chamber depth on fracture strength, possibly differing from the present results due to variations in AM resin and cement type. Bahadır et al[17] evaluated 1-piece endodontic crowns fabricated from a resin intended for interim use, restoring premolars with varying numbers of intact cuspal walls, and reported that the preparation design did not affect fracture load values.

Previous studies on AM 1-piece endodontic crowns intended for definitive use have focused mainly on fabrication trueness and fit.[7,8,16,23] Altinci et al[16] reported favorable internal adaptation for AM 1-piece endodontic crowns, though external surfaces may require more chairside adjustment compared with SM 1-piece endodontic crowns. Other studies recommended 1-mm-wide shoulder margins and 2-mm pulp chamber depth to optimize fit,[7,8] while Xiao et al[23] reported that SM 1-piece endodontic crowns showed higher trueness and better fit than AM 1-piece endodontic crowns for molars with flat shoulder margins and 2-mm pulp chamber preparations.

Limitations of this study included that all preparations used a single tooth type, which may not reflect the effects of anatomic variations on restoration design. In addition, a limited number of margin designs and pulp chamber depths were evaluated, and varied preparation designs could have led to different outcomes. All specimens were fabricated using a single printer and milling unit, which may limit the generalizability of the findings. Additionally, the standardized fabrication parameters could have influenced the measured fracture loads. Consistent with previous studies on the fracture strength of AM dental appliances,[9,18,19,22] the abutments in the present study were AM to ensure standardization and to minimize the variability associated with the use of caries-free natural teeth. Nevertheless, the fracture loads recorded in this study (up to 2052 N) exceeded typical posterior masticatory forces, likely due in part to the elastic deformation of the polymeric resin abutments. This deformation could have altered stress distribution within the specimens, potentially affecting fracture initiation and propagation. Although the fracture patterns were not specifically evaluated in the present study, the use of resin abutments may lead to differences in failure modes compared with natural teeth or more rigid abutments; this should be considered when interpreting the results. Future studies should also include fractographic analysis to clarify fracture mechanisms and material behavior under load. Another limitation was the use of a single resin cement and adhesive system. The cyclic loading protocol could not fully replicate intraoral conditions due to the absence of saliva and thermal fluctuations, and human enamel was not used as the antagonist. Nonetheless, the polyoxymethylene and stainless-steel spheres contacted the cusp slopes, generating shear forces during both cyclic loading and load-to-fracture testing. This study evaluated only the fracture strength of 1-piece endodontic crowns under axial loading; other clinically relevant factors, such as bond strength and microleakage, were not assessed. Because 1-piece endodontic crown failure in clinical settings may also be observed as debonding or dislodgement under lateral forces, focusing solely on fracture testing may limit the clinical interpretation of the findings. Future studies should use natural endodontically treated molars and premolars to better replicate clinical conditions and include different resin cements and aging protocols to simulate various antagonists and thermal cycles for a more comprehensive evaluation of the tested AM resins.

## CONCLUSIONS

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

1. Among the AM specimens, those made from CT had fracture load values similar to or higher than those from other resins, regardless of preparation design. TC specimens had the highest values, when 1-mm-wide shoulder margins were used.
2. Shoulder margins led to higher fracture strength for TC specimens, regardless of the pulp chamber depth. However, there was no clear trend on the effect of margin configuration on the fracture strength of AM specimens.
3. Except for the GR specimens with shoulder margins, 4-mm-deep pulp chamber preparation resulted in fracture load values similar to or higher than those observed with 2-mm-deep preparation. In addition, deeper pulp chambers enabled higher fracture strength with butt joint margins for all materials.
4. The tested 1-piece endodontic crowns showed acceptable fracture load values based on previously reported ranges of masticatory forces.

## REFERENCES


1. Abuabboud O, Marinescu AG, Paven M, et al. Influence of cement thickness, dentine thickness, and intracoronal depth on the fracture resistance of 3D-printed endocrowns: A pilot in vitro study. *Dent J (Basel)*. 2025;13:263.
2. Arafa A, Ziada A. Marginal adaptability and fracture resistance of endodontically treated premolars restored with 3D printed and milled endo-crowns. *Egypt Dent J*. 2023;69:2137–2152.
3. Einhorn M, DuVall N, Wajdowicz M, Brewster J, Roberts H. Preparation ferrule design effect on endocrown failure resistance. *J Prosthodont*. 2019;28:e237–e242.
4. El Ghoul W, Özcan M, Silwadi M, Salameh Z. Fracture resistance and failure modes of endocrowns manufactured with different CAD/CAM materials under axial and lateral loading. *J Esthet Restor Dent*. 2019;31:378–387.
5. El Ghoul W, Özcan M, Tribst JPM, Salameh Z. Fracture resistance, failure mode and stress concentration in a modified endocrown design. *Biomater Invest Dent*. 2020;7:110–119.
6. El-Farag SAA, Elerian FA, Elsherbiny AA, Abbas MH. Impact of different CAD/CAM materials on internal and marginal adaptations and fracture resistance of endocrown restorations with: 3D finite element analysis. *BMC Oral Health*. 2023;23:421.
7. Turker Kader I, Ozer S, Arican B. Advanced 3D insights into the marginal and internal fit of ceramic-filled hybrid endocrowns with variable preparations. *J Esthet Restor Dent*. 2025;37:1753–1761.
8. Turker Kader I, Ozer S, Arican B. An in vitro analysis of marginal and internal fit of 3D-printed permanent molar endocrowns with different preparation designs. *Clin Oral Investig*. 2025;29:319.
9. Nagi N. Comparative evaluation of fracture resistance of different CAD/CAM fabricated endocrowns-in vitro study. *Egypt Dent J*. 2023;69:2917–2922.
10. Dartora NR, de Conto Ferreira MB, Moris ICM, et al. Effect of intracoronal depth of teeth restored with endocrowns on fracture resistance: In vitro and 3-dimensional finite element analysis. *J Endod*. 2018;44:1179–1185.
11. Ibrahim HA, Jasim HH, El Ghoul WA, Vervack V, Sloniewski J. Comparative evaluation of bilayered and monolithic endocrowns: Fracture resistance, failure mode, and stress distribution. *J Mech Behav Biomed Mater*. 2025;168:107033.
12. Beji Vijayakumar J, Varadan P, Balaji L, et al. Fracture resistance of resin based and lithium disilicate endocrowns. Which is better? - A systematic review of in-vitro studies. *Biomater Investig Dent*. 2021;8:104–111.

13. Lenz U, Bacchi A, Della Bona A. Biomechanical performance of endocrown and core-crown restorations: A systematic review. *J Esthet Restor Dent*. 2024;36:303–323.
14. Morimoto S, Arakaki Y, Raggio DP, Özcan M. One-piece endodontic crowns in posterior teeth: An overview of systematic reviews. *J Prosthet Dent*. 2024;134:2103–2116.
15. Fehrenbach J, de Soares JLS, do Nascimento Foly JCS, Miotti LL, Münchow EA. Mechanical performance of endocrown restorations in anterior teeth: A systematic review and network meta-analysis. *Dent Mater*. 2025;41:28–41.
16. Altinci P, Dönmez MB, Çakmak G, et al. Additively manufactured resin-based endocrowns: Effect of material type, margin configuration, and pulp chamber depth on fabrication trueness and fit. *J Dent*. 2025;157:105731.
17. Bahadır HS, Bulut AC, Yılmaz B. Effect of preparation design on the fracture resistance and fracture patterns of 3D printed one-piece endodontic crowns. *J Prosthet Dent*. 2024;132:592.e1–592.e7.
18. Corbani K, Hardan L, Eid R, Skienhe H, Alharbi N. Fracture resistance of three-unit fixed dental prostheses fabricated with milled and 3D printed composite-based materials. *The J Contemp Dent Pract*. 2021;22:985–990.
19. Corbani K, Hardan L, Skienhe H, et al. Effect of material thickness on the fracture resistance and failure pattern of 3D-printed composite crowns. *Int J Comput Dent*. 2020;23:225–233.
20. Demirel M, Diken Türksayar AA, Donmez MB. Fabrication trueness and internal fit of hybrid abutment crowns fabricated by using additively and subtractively manufactured resins. *J Dent*. 2023;136:104621.
21. Donmez MB, Çakmak G, Yılmaz D, et al. Bond strength of additively manufactured composite resins to dentin and titanium when bonded with dual-polymerizing resin cements. *J Prosthet Dent*. 2024;132:1067.e1–1067.e8.
22. Rosentritt M, Rauch A, Hahnel S, Schmidt M. In-vitro performance of subtractively and additively manufactured resin-based molar crowns. *J Mech Behav Biomed Mater*. 2023;141:105806.
23. Xiao P, Zheng Z, Zhang Y, Zeng Y, Yan W. Accuracy and adaptation of one-piece endodontic crowns fabricated through 3D printing and milling. *J Prosthet Dent*. 2024;132:422–433.
24. Taha D, Spintzyk S, Schille C, et al. Fracture resistance and failure modes of polymer infiltrated ceramic endocrown restorations with variations in margin design and occlusal thickness. *J Prosthodont Res*. 2018;62:293–297.
25. Mostafavi AS, Allahyari S, Niakan S, Atri F. Effect of preparation design on marginal integrity and fracture resistance of endocrowns: A systematic review. *Front Dent*. 2022;19:37.
26. Ahmed MAA, Kern M, Mourshed B, Wille S, Chaar MS. Fracture resistance of maxillary premolars restored with different endocrown designs and materials after artificial ageing. *J Prosthodont Res*. 2022;66:141–150.
27. Dinçtürk BA, Garoushi S, Alp CK, et al. Fracture resistance of endocrowns made from different CAD/CAM materials after prolonged fatigue aging. *Clin Oral Investig*. 2025;29:149.
28. Donmez MB, Çakmak G, Atalay S, Yilmaz H, Yilmaz B. Trueness and precision of combined healing abutment-scan body system depending on the scan pattern and implant location: An in-vitro study. *J Dent*. 2022;124:104169.
29. The Crowntec instructions for use brochure. Accessed September 26, 2025. ⟨https://docs.saremco.ch/ifu/saremco_print_crowntec/D600219_GA_CROWNTEC_03–2025_alle%20sprachen_approved.pdf⟩.
30. The FREEPRINT Crown instructions for use brochure. Accessed September 26, 2025. ⟨https://www.detax.com/fileadmin/Content/Dental/Documents/MSDS/Freeprint_Crown/IFU_Freeprint_crown.pdf⟩.
31. Çakmak G, Agovic D, Donmez MB, et al. Effect of number of supports and build angle on the fabrication and internal fit accuracy of additively manufactured definitive resin-ceramic hybrid crowns. *J Dent*. 2023;134:104548.
32. Donmez MB, Okutan Y. Marginal gap and fracture resistance of implant-supported 3D-printed definitive composite crowns: An in vitro study. *J Dent*. 2022;124:104216.
33. Yılmaz D, Çakmak G, Güven ME, et al. Comparison of trueness and margin quality of additively and subtractively manufactured definitive resin-based laminate veneers. *J Prosthet Dent*. 2025;133:184–192.
34. Yilmaz B, Donmez MB, Kahveci Ç, et al. Effect of printing layer thickness on the trueness and fit of additively manufactured removable dies. *J Prosthet Dent*. 2022;128:1318.e1–1318.e9.
35. Çakmak G, Donmez MB, Molinero-Mourelle P, et al. Fracture resistance of additively or subtractively manufactured resin-based definitive crowns: Effect of restorative material, resin cement, and cyclic loading. *Dent Mater*. 2024;40:1072–1077.
36. Güven ME, Donmez MB, Tezcan AN, et al. Performance and durability of additively and subtractively manufactured resin-based onlay restorations after thermomechanical aging. *J Prosthodont* 2024.
37. Güven ME, Çakmak G, Dönmez MB, Yilmaz B. Evaluation of dimensional stability and occlusal wear of additively and subtractively manufactured resin-based crowns after thermomechanical aging. *Appl Sci*. 2023;13:11849.
38. Kashkari A, Yilmaz B, Brantley WA, Schricker SR, Johnston WM. Fracture analysis of monolithic CAD-CAM crowns. *J Esthet Restor Dent*. 2019;31:346–352.
39. Alberto Jurado C, Kaleinikova Z, Tsujimoto A, et al. Comparison of fracture resistance for chairside CAD/CAM lithium disilicate crowns and overlays with different designs. *J Prosthodont*. 2022;31:341–347.
40. van der Bilt A. Assessment of mastication with implications for oral rehabilitation: A review. *J Oral Rehabil*. 2011;38:754–780.
41. Dönmez MB, Kim H-T, Lee Y-H, et al. Effect of barium silicate on mechanical properties, transmittance, and protein adsorption of resin for additive manufacturing containing zwitterionic polymer. *J Prosthet Dent*. 2024;132:465.e1–465.e8.
42. Won S, Ko K-H, Park C-J, Cho L-R, Huh Y-H. Effect of barium silicate filler content on mechanical properties of resin nanoceramics for additive manufacturing. *J Adv Prosthodont*. 2022;14:315.
43. Sabatini GP, Yoon HI, Çakmak G, et al. Mechanical properties and reliability of an additively manufactured resin incorporated with a commercially available ceramic composite concentrate. *J Prosthet Dent*. 2025;133:1089.e1–1089.e7.



**Corresponding author:**
Dr Mustafa Borga Dönmez
Department of Reconstructive Dentistry and Gerodontology
School of Dental Medicine
University of Bern
Freiburgstrasse 7, 3010 Bern
SWITZERLAND
Email: mustafa-borga.doenmez@unibe.ch


**CRediT authorship contribution statement**

**Mustafa Borga Donmez**: Writing - original draft, Writing - review and editing; **Ece Ersöz**: Investigation, Methodology; **Gülce Çakmak**: Investigation, Methodology; **Almira Ada Diken Türksayar**: Formal analysis; **Pinar Altinci**: Writing - review and editing; **Burak Yilmaz**: Conceptualization, Validation, Supervision.


https://doi.org/10.1016/j.prosdent.2025.11.027