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Tooth Structure Removal Associated with Various Preparation Designs for Posterior Teeth



Daniel Edelhoff, Dr Med Dent*/John A. Sorensen, DMD, PhD**

The amount of tooth structure removed for various innovative and conventional preparation designs for fixed prosthodontics was quantified. Four Typodont resin teeth representing maxillary and mandibular premolars and molars were prepared in various abutment designs: adhesive, box (A2); adhesive, wing and groove (A3); mesioocclusal or distoocclusal inlay; mesio-occlusodistal inlay (I3); mesio-occlusodistal onlay; partial crown; half crown (only molars); complete crown, 0.8-mm circumferential tapered chamfer (F1); complete crown, 1.0-mm circumferential rounded shoulder; and complete crown, 1.4-mm axial reduction facial shoulder, 0.7-mm lingual chamfer (F3). After tooth preparation (10 per group), the root was separated from the anatomic crown at the cemento-enamel junction. Removal of tooth structure was measured by gravimetric analysis in a high-precision balance. Preparations A3 and F3 were assigned as abutments for metal-supported restorations, whereas all other preparations were used for all-ceramic restorations. When the mean structure removal of all teeth tested was compared, the adhesive and inlay abutments were the least invasive preparation designs, ranging from approximately 5.5% (A2) to 27.2% (I3) tooth structure removal. Complete crowns required the most invasive preparations, ranging from 67.5% (F1) to 75.6% (F3) tooth structure removal. The tooth structure removal required for F3 retainers was almost 14 times greater than for an A2 preparation. Tooth structure removal was also influenced by the morphology of the tooth. The first comprehensive tooth preparation design classification system was introduced. The measurement system used in this study provides an accurate method of quantifying tooth structure removal for fixed prosthodontic preparations. The innovative preparation designs studied conserved significant amounts of tooth structure, yielding a better prognosis for the restored tooth.

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*Assistant Professor, Department of Prosthodontics, School of Dentistry, Medical Centre, University of Aachen, Germany.

**ODA Centennial Professor of Restorative Dentistry and Director, Dental Clinical Research Center, Department of Prosthodontics, School of Dentistry, Oregon Health Sciences University, Portland.

Reprint requests: Dr John A. Sorensen, School of Dentistry, Oregon Health Sciences University, 611 Southwest Campus Drive, Portland, Oregon 97201-3097. e-mail: sorensenj@ohsu.edu

When missing tooth structure or teeth are replaced, minimal biologic risk should be involved to reestablish function and esthetics. The proven reliability and durability of complete-crown metal ceramics made them the method of choice for posterior single-tooth restorations and fixed partial dentures (FPD).¹ However, this restoration requires considerable reduction of tooth structure. For a metal-ceramic shoulder preparation, a facial tooth reduction of about 1.3 to 1.5 mm is recommended.^{2,3} The introduction of more invasive complete crown preparations for cast-metal and metal ceramics has been correlated with an increase in pulpal complications. In 1966, only 0.4% to 2% radiographic periapical pathologies were found,⁴ whereas in 1970, 2.9% was reported,⁵ and about 10 years later up to 4.0% periapical pathologies were detected.⁶ These results are explained by the increased use of air turbines⁷ and more invasive shoulder or chamfer preparations for metal-ceramic restorations compared to the feather-edge design used in the 1960s and 1970s.⁸

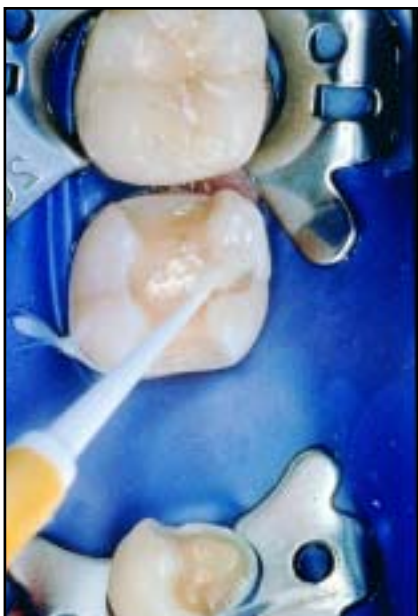


Fig 1 Abutment preparations (mandibular right first premolar and molar) for an all-ceramic inlay-retained FPD.

The mechanical reliability and broad range of indications have made complete crowns the preferred denture retainer. However, wing-shaped retainers with retentive elements such as grooves made of metal have demonstrated a remarkable long-term success rate if the clinical protocol is followed carefully.⁹ Partial preparations like inlays, onlays, or partial crowns are recommended as retainers for short-span FPDs in caries-resistant dentitions.^{10,11} In addition to facilitating superior periodontal health,¹² partial retainers enable preservation of healthy tooth structure.¹³ However,

greater FPD longevity for complete crown retainers compared to inlays has been reported,¹⁴ with secondary caries and loss of retention as the main causes of failures for the latter.^{10,11,14}

A lower number of endodontic complications are associated with less invasive preparations. In a literature review, inlay restorations at 10 years showed a lower rate of loss of pulpal vitality (5.5%) compared to complete crowns (14.5%).⁶ However, a retrospective clinical study on gold inlays reported about a 30% higher rate of endodontic complications in four-surfaced inlays compared to a two-surfaced design.¹⁵ Recurrent caries accounted for the largest number of failures of complete crown and inlay restorations,⁵ with a 7% higher rate for the latter 10 years postplacement.⁶

The increased use of the adhesive technique and preservation of enamel have greatly impacted conservative tooth preparation designs.^{16,17} The inclusion of enamel promotes a superior bond over dentin, lower postcementation sensitivity, improved support of the ceramic restoration, and reduced endodontic intervention.¹⁸ The positive influence of tooth structure preservation on the life expectancy of the pulp was reported in the literature. For cast-metal resin-bonded FPDs, a 0.13% rate of loss of pulpal vitality up to 5 years was reported,¹⁹ compared to 9.1% for complete crown abutments in the same period.²⁰

The combination of highly translucent prosthodontic materials

and resin composite cements has enhanced the use of the adhesive technique and launched a new era of restorative treatment options^{21–24} with promising initial clinical results.²⁵ For the first castable glass-ceramic system, a highly invasive circumferential axial reduction for complete crowns was considered necessary to achieve sufficient strength and esthetics.^{26,27} New *in vitro* findings and a better understanding of stress formation in all-ceramic restorations^{28,29} led to less invasive preparations extended to existing systems.³⁰ Additionally, the improved physical properties of newer ceramics with excellent translucency enabled reduced axial preparation depth and new preparation designs.³¹ The reduced invasiveness of these resin-bonded inlay-retained FPDs makes them an appealing alternative to conventional preparations in cases where the residual dentition exhibits low caries activity (Fig 1).^{32,33}

The purpose of this study was to gravimetrically quantify the amount of tooth structure removed for new and conventional (includes crowns) preparations for posterior FPD retainers.

Method and materials

Four different posterior resin tooth morphologies—maxillary right first premolar and molar, mandibular left second premolar and molar (Nissin Kilgore)—were used for the study. The homogeneous structure of artificial teeth helped avoid undesirable individual differences

like morphologic deviations, extension of the pulp and dentin tubules, and liquid content of natural teeth, which may influence gravimetric measurements. Furthermore, a standardized preparation technique can be performed because of lack of decay and preexisting fillings. To approximate the clinical situation, the teeth were prepared on a Typodont model (Nissin Kilgore) with a missing mandibular left first molar.

Resin materials tend to absorb water depending on storage conditions.³⁴ This could affect the gravimetric evaluation of resin teeth after preparation with turbine/spray application. Therefore, a pilot study was performed to measure the effect of storage conditions on water uptake and weight change of the resin teeth. The relative weight increase after 10-day water storage at 23°C was determined for two types of the unprepared resin teeth (maxillary first molar and premolar). The weight of unprepared teeth (10 per group) increased after 10-day water storage, ranging from 2.05% (molar) to 2.54% (pre-molar). After 24-hour storage at 60°C in an incubator, the weight of the resin teeth decreased below the level of those stored at room temperature without water contact. Accordingly, all resin teeth in the study were prepared under turbine/spray application and dried in an incubator under the given conditions.

Ten teeth were prepared per group, all by one of the authors. The codes for the preparation designs and the armamentarium employed in the study are given in Table 1 (Figs 2 to 8). When possible, a transparent

template was employed as a guideline for the preparation. The preparation depth was controlled with the template and a scaled periodontal probe (UNC15, Hu-Friedy). After completion of the preparation, the cemento-enamel area was marked, and the root was cut off with a precision low-speed saw (Isomet, Buehler) and refined with a carbide cutter (H29DF-023, Brasseler). Prior to the determination of the weight in a high-precision balance (type B6, E. Mettler), the prepared, decapitated teeth were cleaned with isopropanol (70%) and dried with air pressure.

As a reference, the mean weight of unprepared decapitated anatomic crowns (10 per tooth type) was employed. The percentage of structure removal (R_s) was calculated by the following equation:

$$R_s = \frac{W_0 - W}{W_0} \cdot 100$$

where W_0 = the mean weight of 10 unprepared decapitated anatomic crowns, and W = mean weight of 10 prepared decapitated anatomic crowns. The means and standard deviations of tooth structure removal for preparation design were analyzed with analysis of variance (ANOVA).

Table 1 Codes and armamentarium employed for the preparation designs

Code	Preparation design	Dimensions (mm)	Burs	Reference
Adhesive attachments, inlays, and onlays				
A2 (Fig 2)	Adhesive attachment, box (all ceramic)	Margin: 0.5 occlusal from CEJ; height/width: 5.0 × 4.0; depth of box floor: 1.7	8847KR-31-016, Sonicsys approx. tip No. 4*	24
A3 (Fig 3)	Adhesive attachment, wing/two grooves (cast metal), chamfer finish line	Margin: 1.0 occlusal from CEJ; 0.5 lingual reduction	878-31-010, 8878-31-010, 8856-31-012, 8862-31-012, 88011-31-021	35
I2 (Fig 3)	MO or DO inlay abutment, exclusion of transverse ridge or central groove in molars (all ceramic)	Margin: 0.5 occlusal from CEJ; 2.0 occlusal isthmus depth (central groove); occlusal isthmus floor width: 2.0 (pre-molars), 3.0 (molars); proximal box: 5.0 × 4.0 × 1.5 (rounded internal angles); 6° axial convergence (walls)	6856-31-016, H375R-016, H158-014, Sonicsys approx. tip No. 4*	32,33
I2 (Fig 4) [†]	MO inlay abutment, inclusion of transverse ridge or central groove (all ceramic)	Same as I2, inclusion of transverse ridge or central groove	Same as I2	
I3	MOD inlay abutment (all ceramic)	Same as I2 for pontic-side box; opposing proximal box: 4.5 × 3.5 × 1.5 (rounded internal angles)	Same as I2, plus 5858-31-014, Sonicsys approx. tip No. 3*	32,33
O (Fig 4)	MOD onlay abutment (all ceramic)	Same as I3; additional occlusal reduction: 1.5 (functional cusps), 1.0 (nonfunctional cusps); 1.0 chamfer finish line (overlay)	Same as I3	
Crowns				
PC (Fig 5)	Partial-crown abutment (all ceramic)	Similar to O; 1.5 additional reduction of functional cusp; margin: 0.5 occlusal from CEJ; 0.8 chamfer finish line	Same as O, plus 6878-31-016, 8878-31-016	
HC (Fig 6) [†]	Half-crown abutment (all ceramic)	Margin: 1.0 occlusal from CEJ; 0.5 lingual reduction	828-31-030, 6847KR-31-016, 8847KR-31-016, H336-31-016, 1089-31-012, 379-31-023, 379EF-31-023	31,33
F1 (Figs 13 and 14)	Complete crown (all ceramic), chamfer finish line	Margin: 0.5 occlusal from CEJ; 0.8 margin depth; 1.5 occlusal clearance; 6° axial convergence	828-31-030, 6878-31-016, 8878-31-016, 379-31-023, 379EF-31-023	29,30
F2 (Figs 7 and 8)	Complete crown (all ceramic), rounded shoulder finish line	Margin: 0.5 incisal from CEJ; 1.0 margin depth; 1.5 occlusal clearance; 6° axial convergence	828-31-030, 847KR-31-016, H336-31-016, 1089-31-012, 379-31-023, 379EF-31-023	31,36
F3 (Figs 7 and 8)	Complete crown (metal ceramic), facial: rounded shoulder, oral: chamfer finish line	Margin: 0.5 occlusal from CEJ; margin depth: 1.4 (facial), 0.7 (lingual); 2.0 occlusal clearance; 6° axial convergence	828-31-030, 847KR-31-016, H336-31-016, H283-31-012, H158-31-014, 1089-31-016, 379-31-023, 379EF-31-023	3,37

*Manufactured by KaVo.

[†]Molars only.

CEJ = cementoenamel junction; MO = mesio-occlusal; DO = disto-occlusal; MOD = mesio-occlusodistal.



Fig 2 Proximal view of A2 abutment design on a maxillary right first premolar. Vertical dimension of the proximal box from gingival margin to marginal ridge is 5 mm.



Fig 3 Left: occlusal view of adhesive attachment design (A3) for resin-bonded cast-metal FPD on a maxillary right first premolar. Right: occlusal view of a two-surfaced inlay abutment design (I2).



Fig 4 Left: proximal view of I2 abutment design on a maxillary right first molar. Vertical dimension of proximal box from gingival margin to marginal ridge is 5 mm. Right: proximal view of onlay abutment preparation design (O) on a maxillary right first premolar. Vertical dimension of proximal box adjacent to the pontic is 5 mm.



Fig 5 (left) Occlusal view of partial-veneer crown abutment design (PC) on a maxillary right first molar.



Fig 6 (right) Lateral view of the half-crown preparation design (HC) on a mandibular left first molar.



Fig 7 (left) Lateral view of all-ceramic complete crown abutment design (F2) with 1-mm circumferential rounded shoulder (left) and metal-ceramic complete crown abutment design (F3) with 1.4-mm labial rounded shoulder and lingual 0.7-mm chamfer (right) on a maxillary right first molar.



Fig 8 (right) Occlusal view of F2 abutment design (left) and F3 abutment design (right) on a maxillary right first molar.

Results

The results for the different teeth are given in Figs 9 to 12. The mean amount of tooth structure removal for preparation design increased in the following order: A2 (5.5%), A3 (10%), I2 (20%), I3 (27.2%), HC

(35.5%), O (39%), PC (46.7%), F1 (67.5%), F2 (72.3%), and F3 (75.6%).

These results show that for a metal-ceramic crown retainer preparation, almost eight times more tooth structure must be removed compared to an adhesive wing-and-groove attachment for a resin-

bonded cast-metal FPD. The new half-crown preparation assigned for all-ceramic FPDs required a similar amount of tooth structure removal as the onlay and cost approximately half of the tooth structure of a complete crown design. Preparations for metal-ceramic crowns (F3) with an

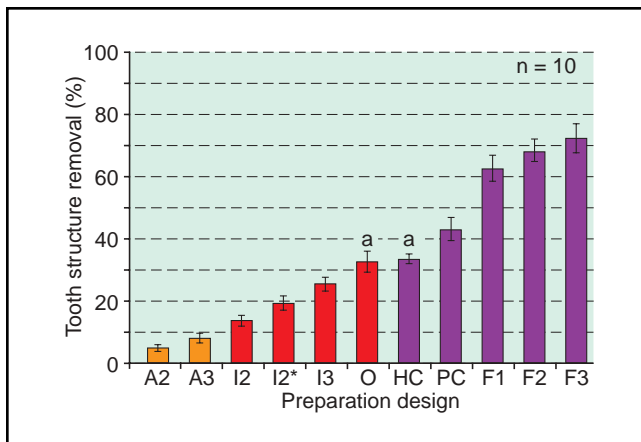


Fig 9 Tooth structure removal for a maxillary right first molar for various preparation designs. Columns with the same superscripted letter were not statistically significantly different.

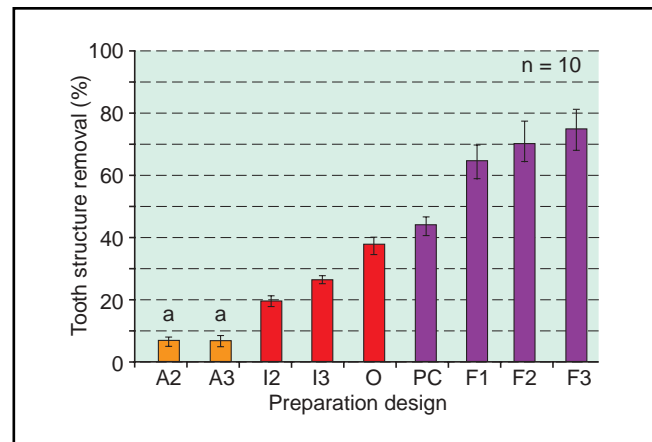


Fig 10 Tooth structure removal for a maxillary right first premolar for various preparation designs. Columns with the same superscripted letter were not statistically significantly different.

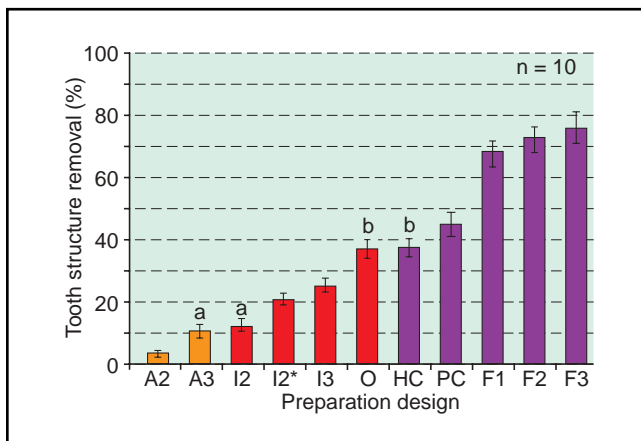


Fig 11 Tooth structure removal for a mandibular left second molar for various preparation designs. Columns with the same superscripted letter were not statistically significantly different.

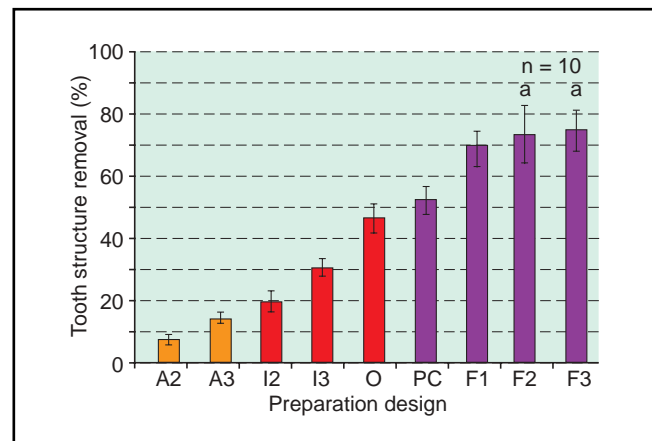


Fig 12 Tooth structure removal for a mandibular left second premolar for various preparation designs. Columns with the same superscripted letter were not statistically significantly different.

occlusal ceramic veneer showed an 8% higher amount of tooth structure removal than the F1 preparation design for all-ceramic crowns. The reduced occlusal extent of I2 preparation (Table 1), excluding the transverse ridge or the central groove in

molars, resulted in a preservation of hard tissue of about 6% (maxillary first molar) and 8% (mandibular second molar). The removal of tooth structure was also influenced by the tooth morphology. Preparation A3, for example, varied significantly, in

premolars from 7.3% (maxillary first; Fig 10) to 13.8% (mandibular second; Fig 12), and in molars from 7.8% (maxillary first; Fig 9) to 10.9% (mandibular second; Fig 11).

Discussion

Previous studies have described different methods for quantification of tooth structure removal of preparation designs for metal-supported restorations.^{13,38} Given the accuracy, ease, and simplicity, gravimetric analysis was employed to measure tooth structure removal. It should be noted that in these ideal preparation designs, only the specific requirements of the material were considered as a factor for tooth structure removal. Beyond that, other important clinical criteria, such as condition of the tooth, esthetic and functional aspects, orientation of the tooth, tooth retention, reconstruction of the occlusion, and patient desires, control the preparation design.

In comparison with a previous study using a similar test method¹³ for various gold alloy-based FPD preparations, greater tooth structure removal was found with the new preparation designs employed in the present study, especially for the partial preparations. For a mesio-occlusodistal gold inlay FPD retainer, an average of 16% structure removal was measured, compared to an average of about 27% in the present study. The onlay (34% versus 39%) and the partial crown (38% versus 47%) preparation designs were similar. The higher amount of tooth structure removal found in the present study can be explained by the specific mechanical requirements of all-ceramic restorations. The partial abutment designs for all-ceramic restorations (A2, I2, I3, O, PC, HC)

differ from those generally employed for all-ceramic single restorations and metal-supported systems.

Clinical studies with all-ceramic FPDs have shown that the mechanical properties of the material require a defined minimum of the vertical dimension of the connector.^{31,39} Finite element analysis supports these clinical recommendations: When a load is applied on the pontic area, the highest stresses occur within the connector and gingival surface of the pontic surface.^{24,28} According to the law of beams, the vertical dimension of the connector increases to the third power the resistance to flexure of the connector and pontic, whereas the horizontal extension only has a linear effect.⁴⁰ Therefore, an extension of 5 mm in vertical dimension was considered the minimum connector height for the pontic and influenced the proximal box design adjacent to the pontic in partial-coverage prostheses (Figs 2 and 4). However, complete crown preparations for metal ceramics (F3) required greater tooth structure removal than those used for certain all-ceramic systems (F1).³⁰

The higher results for F3 preparations in the present study (75.7% to 77.8%) compared to those of a previous investigation (60% to 70%)¹³ occurred because of different preparation designs with no occlusal veneering and a 1.2-mm shoulder.¹³ Tooth reduction of only 56% was measured for a complete gold crown when a 0.6-mm preparation depth was employed.¹³ Endodontic complications can also occur dependent on the area of the tooth structure

removal. In contrast to an extracoronary circumferential preparation, the intracoronary preparation features, such as boxes for an inlay-retained FPD, have a higher risk of proximity to the pulp, especially if the abutment teeth are not in a parallel orientation. Only abutment teeth with a normal orientation were prepared in the present study. The orientation of the abutment teeth can have a considerable influence on the amount of structure removal. Increasing convergence of the abutment teeth reduces structure removal when a complete crown retainer is employed and increases it when partial-coverage preparation designs are used.¹³

In this context, the half-crown preparation³³ is a promising design for molars in situations where an angulated abutment tooth has to be aligned to reestablish the occlusion (Fig 6). The extracoronary preparation has only a minor risk to the pulp. Clinically, the preparation should be guided by a template fabricated according to a diagnostic waxup. This procedure economizes sound tooth structure removal and ensures a consistent thickness of the restorative material.⁴¹ In many situations, because of the angulation only a small amount of tooth structure has to be removed occlusally, preserving the enamel layer as an excellent bonding substrate. This preparation design is used by the authors in patients with low caries activity.

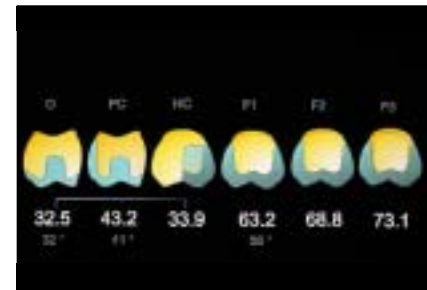
These conservative preparation designs enable great advancement in economy of sound tissues (Figs 13 and 14) and maintenance of pulpal



Fig 13 Comparison of tooth structure removal associated with the different preparation designs for a mandibular left second premolar. * = tooth structure removal for preparations performed for cast-metal restorations.¹³



Fig 14 Comparison of tooth structure removal associated with the different preparation designs for a maxillary right first molar. * = tooth structure removal for preparations performed for cast-metal restorations¹³; values connected with a line were not statistically significantly different.



vitality, decreasing the biologic cost in comparison to traditional, more invasive fixed prosthodontic designs.

Conclusions

- Considering tooth structure preservation, adhesive attachments and inlay retainers are preferable.
- The tooth structure removal required for a metal-ceramic complete crown (F3) retainer was almost 14 times greater than for an adhesive attachment (A2) preparation and approximately 20% greater than for a complete gold crown.
- All-ceramic crown preparation designs were significantly less invasive than metal-ceramic crowns with a gold-based substructure.

- The new half-crown preparation for all-ceramic FPDs had similar tooth structure removal to the onlay and sacrificed approximately half the tooth structure of a complete crown design.
- Partial-coverage preparations for posterior all-ceramic FPD retainers showed a higher invasiveness than cast-metal systems because of the specific mechanical requirements.
- The removal of tooth structure was also influenced by the tooth morphology.

The findings of this *in vitro* study must be considered for sound clinical tooth preparation design criteria. Use of the innovative preparation designs evaluated will result in conservation of sound tooth structure.

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