Relative amount of tooth structure removal in different partial- and full-crown preparation designs

Adrian Roman Weber, Dr med dent, MAS,a Burak Yilmaz, DDS Phd, b,c,d Urs Brägger, Prof em Dr med dent, e Martin Schimmel, Prof Dr med dent, MAS, f,g Samir Abou-Ayash, PD Dr med dent h

a Specialization candidate, Department of Reconstructive Dentistry and Gerodontology, School of Dental Medicine, University of Bern, Bern, Switzerland
b Associate Professor, Department of Reconstructive Dentistry and Gerodontology, School of Dental Medicine, University of Bern, Bern, Switzerland
c Associate Professor, Department of Restorative, preventive and Pediatric Dentistry, School of Dental Medicine, University of Bern, Bern, Switzerland
d Adjunct Professor, Division of Restorative and Prosthetic Dentistry, The Ohio State University, Ohio, USA
e Professor emeritus, Department of Reconstructive Dentistry and Gerodontology, School of Dental Medicine, University of Bern, Bern, Switzerland
f Professor, Department of Reconstructive Dentistry and Gerodontology, School of Dental Medicine, University of Bern, Bern, Switzerland
g Privat Docent, Division of Gerodontology and Removable Prosthodontics, University of Geneva, Geneva, Switzerland
h Senior Lecturer, Section for Digital Implant- and Reconstructive Dentistry [DIReD], Department of Reconstructive Dentistry and Gerodontology, School of Dental Medicine, University of Bern, Bern, Switzerland
Corresponding author:
Dr. med. dent. Adrian Roman Weber
Department of Reconstructive Dentistry and Gerodontology, School of Dental Medicine, University of Bern, Switzerland
Freiburgstrasse 7
3010 Bern, Switzerland
Phone: +41316640843
Email: adrian.weber@zmk.unibe.ch

Submitted April 6, 2020; accepted May 13, 2021.

ABSTRACT

Purpose: To assess the effect of tooth morphology on the amount of tooth structure removal and the effect of different assessment methods on the detected amount of removed tooth structure. Materials and Methods: Eight test groups (n = 10) of standardized artificial teeth were prepared for partial and full crowns. All teeth were prepared by the same operator following predefined preparation parameters. Tooth structure removal was measured using three different assessment methods: digital volumetric analysis (DVA), weight analysis (WA), and combined computer-aided manufacture and weight analysis (CAMWA). Nonparametric repeated-measures analysis of variance and post hoc analyses were used to determine the influence of tooth morphology and assessment method on the detected amount of tooth structure removal. Results: For partial crown preparations, only the tooth morphology had a significant impact on the detected amount of tooth structure removal (P < .0001), not the different assessment methods used (P = .08). Tooth structure removal was not significantly different between the canine and incisor groups, but was for the other groupwise comparisons. For full crown preparations, the tooth morphology (P = .047) and different assessment
methods ($P = .01$) had an impact on the detected tooth structure removal. However, only a few groupwise comparisons reached the significance level. **Conclusion:** The amount of tooth structure removal depended on the tooth morphology and the type of assessment method, which should be taken into account when comparing results across studies. The detected amount of tooth structure removal was below the values described in the literature, independent of the assessment method used. *Int J Prosthodont* 2021. doi: 10.11607/ijp.7049

**INTRODUCTION**

As a result of improved dental and oral health in industrialized countries, many individuals preserve their natural teeth, even into advanced age. However, due to their prolonged survival in the oral cavity, those teeth are influenced by extrinsic factors. Following caries lesions and biomechanical wear, teeth restoration with indirect restorations, such as partial or full crowns, may be indicated. Studies have shown that up to 70% of tooth structure is lost in conventional full crown preparations. When a conventional full crown preparation is planned, clinicians should consider the invasiveness of this preparation design. Therefore, it is important to establish less invasive methods for circular preparation or methods for adequate evaluation of the lost tooth structure.

The clinical success of indirect restorations is influenced by the amount of tooth structure removed during tooth preparation. In the past, various parameters for partial- and full-crown preparations have been proposed. These parameters are mainly based on tooth morphology, functional and aesthetic aspects, and the choice of restorative material. The extent of tooth structure removal during preparation is directly related to the risk of post-operative complications such as pain, pulpitis, necrosis, devitalization, and even abutment tooth loss. Moreover, it was reported that tooth preparations may lead to the loss of vitality and periapical inflammation in 14% of abutment teeth after 4 to 13 years post-intervention. To minimize these risks, every tooth preparation should be planned in detail, avoiding...
unnecessary tooth structure removal. Tooth morphology has been shown to have an impact on
the amount of tooth structure removal in previous studies.\(^3, 4\) However, these previous studies
only compared the effect of teeth on the amount of tooth structure removal within certain
quadrants and by using only the weight analysis method. No studies focused on the effect of
central incisor, canine, premolar and a molar’s morphology on the amount of tooth structure
removal for certain preparation designs by using different analyses.

Due to ongoing developments in dental ceramic systems, a wide range of high-strength and
esthetic materials are now available. These materials can be processed and applied intraorally
at thicknesses lower than conventional restorative materials, such as metal alloys with
ceramic veneering.\(^14\) Furthermore, the evolution of adhesive dentistry has led to the successful
application of those materials in situations with compromised amounts of remaining tooth
structure.\(^15\) Thus, invasive and retentive preparations required for metal-ceramic systems can
now be avoided.

Over the previous decades, several studies, which examined the amount of tooth structure
removal for full- and partial-crown preparations have been published.\(^3, 4, 16, 17\) The two most
commonly applied types of analyses were the weight analysis (WA) or digital volumetric
analyses (DVA). The weight and/or volumetric difference after tooth preparations was
commonly expressed as the relative amount of tooth structure removal. By using the WA, the
coronal parts of artificial teeth were separated at the level of the cemento-enamel junction
(CEJ) and smoothened at the basal portion. Afterwards, the specimens were weighed before
and after partial- and full-crown preparations and the relative weight loss calculated.\(^3, 4, 16, 17\)
The DVA was based on the digitization of non-prepared and then prepared specimens by
using optical scanners. After digitization, the relative amount of tooth structure removal was
calculated either by superimposing or by comparing the overall volume of two respective
specimens.\(^16, 17\) When the WA or DVA were used, the reported relative amounts of tooth
structure removal caused by full-crown preparations were very heterogeneous (42-75.6%).\(^3, 4,\)
It is not well-known whether such a large variation in the outcome is sourced by the amount of tooth structure removed or the analyses used to determine the amount lost. Accordingly, it is not clear whether these assessment methods are reliable, particularly the more recent DVA, which involves the use of digital data for volume analysis. To understand the amount of removed tooth structure more clearly, WA and DVA can be combined by scanning the tooth before and after it is prepared and both scan files can be CAM in resin to detect the difference in their weight and accordingly the amount of tooth structure removal. The findings of this combined method can help verify the detected amount of removed tooth structure when the DVA or WA are used. The changes in percent volume and percent weight can also be compared to each other when the combined method is used. Such a comparison may allow for an improved evaluation and understanding of the amount of removed tooth structure.

Therefore, the present study aimed to analyze the relative amount of tooth structure removal during partial- and full-crown preparations with WA, DVA and a novel combined assessment method which included the weight analysis of CAM-fabricated teeth (CAMWA), combining the WA and DVA when teeth with varying morphologies were prepared.

The first null hypothesis of this study was that the tooth morphology would not affect the amount of tooth structure removal.

The second null hypothesis of this study was that the type of assessment method would not affect the detected amount of removed tooth structure.

MATERIALS AND METHODS

In the present comparative in vitro study, partial- and full-crown preparations were performed at the Department of Reconstructive Dentistry and Gerodontology, School of Dental Medicine, University of Bern, Switzerland.

Experimental design
Four different types of maxillary artificial teeth (Nissin Kilgore International Inc.) were used for the study (Fig.1) and subdivided into eight test groups (n = 10 each) for partial- and full-crown preparations: maxillary right central incisor veneer (CIV), maxillary right canine veneer (CAV), maxillary left second premolar partial-crown (PMP), maxillary left first molar partial-crown (FMP), maxillary right central incisor full-crown (CI), maxillary right canine full-crown (CA), maxillary left second premolar full-crown (PM), and maxillary left first molar full-crown (FM) (total n = 80). A non-prepared tooth for each group served as a control (CIV, CAV, PMP, FMP, CI, CA, PM, FM; n = 1 each).

**Partial- and full-crown sample preparations**

All teeth in each group (n = 10) were prepared (Tab.1-3) with identical diamond burs (jota kit 1424; Jota AG) by the same prosthodontist using a 3.5× optical magnification. The prepared teeth were mounted on a dentate maxillary model during the preparation. The applied burs were specifically designed for less invasive partial- and full-crown preparations, including a 1 mm wide rounded shoulder and a reduced flank angle to minimize the risk of an excessive taper (Fig.2). For CIV and CAV, the teeth were prepared for a veneer with the following preparation parameters: margin preparation 0.5 mm above the cementoenamel junction (CEJ), facial axial wall reduction of 0.8 mm (cervical third) and 1.0 mm (middle to incisal third), incisal reduction of 1.5 mm (Fig.3, Tab.1). The PMP and FMP teeth were prepared for an overlay reconstruction by using following parameters: margin preparation 0.5 mm above the anatomical equator (AE), axial reduction of 1.0 mm, convergence angle of 6°, and incisal/occlusal clearance of 1.5 mm (Fig.4, Tab.2). For full-crown preparations, the following parameters were applied as previously reported: margin preparation 0.5 mm above the cementoenamel junction (CEJ), axial reduction of 1.0 mm, convergence angle of 6°, and incisal/occlusal clearance of 1.5 mm (Fig.5, Tab.3). These parameters have also been applied in previous studies on tooth structure removal. The amount of preparation was controlled...
by using a putty silicone key and a 1 mm scaled periodontal probe. A non-prepared tooth served as a reference for each group (Fig. 6). After preparation, the CEJ was assessed at 3.5x optical magnification on all samples, color-coded, and the coronal part was separated from the radicular portion along the axis of the CEJ (Fig. 7). The basal portion was then smoothened with a diamond bur (558.FG.013/015; Jota AG). This procedure was performed for all specimens and reference teeth. Tooth structure removal was detected at multiple time points, applying three assessment methods (DVA, WA, CAMWA).

**Assessment methods (DVA, WA, CAMWA)**

For DVA, all samples were sequentially fixed on a resin holder and scanned with a 3D laboratory laser scanner (S600 Arti; Zirkonzahn GmbH). According to the manufacturer’s instructions, the scanner’s precision is less than or equal to 10 µm, which was also reported in the literature. Since the basal portion of the samples at the level of the CEJ was not detected by the 3D scan, automatic digital closure of the sample surface was performed by using a manufacturer-specific software (Zirkonzahn Scan; Zirkonzahn GmbH), by calculating the shortest distance between opposing surface points of the CEJ. The surface scans were subsequently imported into a volumetric analysis software (Meshmixer, Autodesk Inc.). The initial volume (non-prepared tooth crown up to the CEJ) of each reference tooth was determined, followed by assessments of each prepared specimen (prepared tooth crown up to CEJ). Subsequently, relative differences between the respective controls and specimens were calculated.

For WA, each prepared sample (coronal portion of the prepared tooth crown up to CEJ) and the references (coronal portion of the non-prepared tooth crown up to CEJ) were weighed on an electric precision scale (MS104TS/M00; Mettler-Toledo GmbH) and the relative weight loss (difference between the prepared and non-prepared tooth crown up to CEJ) in each group was calculated in %.
For CAMWA, a physical counter-control was performed. The method based on the scan data obtained in DVA, where the scans of specimens were converted into physical samples and references via CAD-CAM. Therefore, all specimens of the digitized and basally closed samples from DVA were copy-milled (M1 Wet Heavy Metal; Zirkonzahn GmbH) from a homogenous resin CAD-CAM blank (Try in 1, 95H16; Zirkonzahn GmbH) and weighed (Fig. 8). Subsequently, the relative weight loss in % was calculated as described in WA. To avoid assessment bias, the scanner and the electric precision scale were re-calibrated after every fifth assessment by taring as proposed in the user manuals.

The amount of tooth structure removal was detected for all specimens by using each of the 3 different methods.

**Statistical Analysis**

Data analysis was performed by means of descriptive analyses and statistical inference comparing groups and methods.

For descriptive analyses means and standard deviations (SDs) were calculated, determining the detected tooth structure removal per group (CIV, CAV, PMP, FMP, CI, CA, PM, FM) for each assessment method (DVA, WA, CAMWA) separately. For each group (CIV, CAV, PMP, FMP, CI, CA, PM, FM), overall mean tooth structure removal was calculated combining the results from all assessment methods (DVA, WA, CAMWA). A non-parametric repeated measures ANOVA by Brunner and Langer was performed on a global scale including the factors: group and assessment method. Post-hoc exact Mann-Whitney tests were performed to compare groups, if the global ANOVA revealed a significant effect for group. Post-hoc pairwise repeated measures ANOVAs were performed to compare different assessment method, if the global ANOVA revealed a significant effect for method. Throughout, p-values less than 0.05 were considered statistically significant. P-values of all
pairwise comparisons were adjusted for multiple testing using the adjustment method by Holm. All analyses in this report were performed with the statistics software R, version 3.5.0.

RESULTS

Descriptive analysis of detected tooth structure removal

The digitally detected relative volume loss (DVA) for the prepared samples increased in the following order (mean ± SD): CAV (8.72 % ± 0.52), CIV (9.59 % ± 0.98), PMP (14.04 % ± 1.35), FMP (17.64 % ± 1.55), CA (28.73% ± 3.99), CI (32.16% ± 3.34), PM (32.30% ± 0.72), FM (33.74% ± 2.92). The detected relative weight loss (WA) increased in the following order: CAV (9.03 % ± 3.17), CIV (10.04 % ± 2.66), PMP (14.81 % ± 2.63), FMP (18.48 % ± 1.32), CA (29.48% ± 4.04), CI (33.07% ± 4.96), PM (32.44% ± 8.00), FM (34.4% ± 4.18).

The detected relative weight loss (CAMWA) for the CAM fabricated samples increased in the following order: CAV (9.51 % ± 2.45), CIV (10.35 % ± 1.83), PMP (14.64 % ± 2.61), FMP (19.16 % ± 1.55), CA (29.89% ± 4.00), PM (33.18% ± 3.42), CI (33.56% ± 5.19), FM (35.56% ± 2.25).

The lowest amount was observed in the CAV (9.09 % ± 2.28), followed by the CIV (9.99 % ± 1.90), the PMP (14.50 % ± 2.22), the FMP (18.43 % ± 1.56), the CA (29.37% ± 3.91), the CI (32.64% ± 4.45), the PM (32.93% ± 4.88) and the FM (34.56% ± 3.20).

The mean relative amount of detected tooth structure removal combining all types of assessment methods is provided in figure 9 for partial-crown preparations and in figure 10 for full-crown preparations.

Comparative analysis of tooth structure removal

When comparing the three assessment methods for the detected tooth structure removal in partial-crown preparations, the least overall tooth structure removal was observed with the digital volumetric analysis (DVA: 12.50% ± 3.80), followed by the WA of initial samples (W13.09% ± 4.56) and with the CAMWA (13.42% ± 4.41) (Fig. 11). There were no
significant differences comparing the detected amount of tooth structure removal for partial-crown preparations with the assessment methods DVA-CAMWA, although the p-value was small (p = 0.08).

When comparing the three assessment methods for the detected tooth structure removal in full-crown preparations, the least overall tooth structure removal was observed with the DVA: (31.73% ± 3.44), followed by the WA: 32.35% ± 5.62) and the CAMWA(33.05% ± 4.24) (Fig. 12). The repeated measures non-parametric ANOVA revealed significant differences in the detected tooth structure removal between types of assessment methods (p = 0.047). Holm-corrected post-hoc tests then showed significant differences only for group FM between DVA and CAMWA, as well as WA and CAMWA (p = 0.01 for both comparisons).

For partial-crown preparations, the repeated measures non-parametric ANOVA revealed significant differences in the detected tooth structure removal between the groups (p < 0.0001). The group-wise exact Mann-Whitney post-hoc tests demonstrated no differences between the CAV and CIV groups for all types of analyses. All other groups differed significantly from each other (Tab. 4).

For full-crown preparations, the repeated measures non-parametric ANOVA revealed significant differences in the detected tooth structure removal between the groups (p = 0.01). Since the repeated measures ANOVA was statistically significant, group-wise exact Mann-Whitney post-hoc tests were performed to compare all groups with each other. Only one post-hoc comparison of means was significant, comparing CA and FM (p = 0.04) within assessment method CAMWA (Tab. 5).

**DISCUSSION**

The relative amount of tooth structure removed was significantly influenced by the tooth morphology. Therefore, the first null hypothesis was rejected. The detected amount of tooth structure removal was significantly influenced by the applied assessment method. Therefore, the second null hypothesis was rejected.
Tooth structure removal during partial-crown preparation ranged from 8.72% for prepared maxillary right canines up to 19.16% for prepared maxillary left first molars. Tooth structure removal during full-crown preparation ranged from 28.73% for prepared maxillary right canines up to 35.56% for prepared maxillary left first molars.

Edelhoff and Sorensen previously examined tooth structure removal while performing various types of partial- and full-crown preparations in artificial teeth of the anterior and posterior maxilla and mandible. They ascertained the amount of tooth structure removed applying weight analysis, and the detected tooth structure removal ranged from 3% for partial-crown preparations up to 75.6% for full-crown preparations. When applying the preparation designs used in the present study, they reported significantly higher tooth structure removal. For the preparation of an anterior veneer, they found mean tooth structure removal of 22.1%, and for a similar onlay preparation design 39%. 70% of tooth structure was removed for an all-ceramic full-crown preparation design in anterior teeth (maxillary left central incisor, maxillary left canine, mandibular left central incisor), while 72.3% of tooth structure was removed for an all-ceramic full-crown preparation design in posterior teeth (maxillary right first molar, maxillary right first premolar, mandibular left second molar, mandibular left second premolar). In the present study, the reported ratio of tooth structure removal for full-crowns was 2.2 times higher than for an overlay and 3.5 times higher than for a veneer. This data is similar to the results of the above-mentioned study. When the relative amount of tooth structure removal between the present study was compared with the results in the study by Edelhoff and Sorensen, it was observed that the detected amount of tooth structure removal in their study was almost twice as high, although similar preparation parameters were used. This fact underlines the potential influence of the operator on the amount of tooth structure removal.

Al-Fouzan and Tashkandi investigated tooth structure removal following three different preparation designs in extracted natural maxillary and mandibular anterior and posterior teeth,
by using both micro-CT and digital volumetric analyses. They detected tooth structure removal of 30.28% with partial-crown preparations and up to 65.26% with full-crown preparations. Applying the preparation design relevant to the present study, the reported tooth structure removal for an all-ceramic full-crown preparation design (maxillary central incisor) was considerably higher (65.26%). The amount of tooth structure removal was 2.1 times higher for full-crowns than for partial-crowns. These findings show similar proportions compared to the present study. Preparing natural teeth offers the advantage of the closest possible clinical simulation for an in vitro design but has the disadvantage of less standardized samples. However, to achieve an optimal standardization of the samples, artificial teeth were examined in the present study.

Monaco et al. investigated tooth structure removal in artificial maxillary molars. The samples were prepared particularly considering material properties (metal ceramic crowns, zirconia all-ceramic crowns, lithium disilicate crowns) for seven full-crown and one partial-crown design. The percentage of tooth structure removed was evaluated by weight and then volumetric analyses. The data obtained by the volumetric method were similar to those obtained by the weight analysis. They reported values from 17.33% for the partial-crown design up to 45.1% for a metal-ceramic full-crown preparation. For the preparation design relevant to this study, they reported values of 17.33% for a partial-crown design and up to 43.50% for a full-crown preparation design. As a more invasive partial-crown preparation design was used in the present study, the reported amount of relative tooth structure removal was slightly higher, and for the full-crown preparation design, the detected amount of tooth structure removal was lower.

One reason for the heterogeneous results might be the various morphologies of the artificial teeth produced by independent manufacturers. Considering the results of the present study, the tooth morphology seems to influence the amount of tooth structure removal during preparation. Except for the investigation by Al-Fouzan and Tashkandi, who evaluated
extracted teeth, artificial teeth from various manufacturers were examined in the above-described studies. Analyzing the influence of different methods for the determination of coronal tooth structure removal with non-standardized specimens would not have been possible. Consequently, artificial teeth instead of extracted teeth were chosen in the current study. If identical artificial teeth were used in existing studies, the results might have been more homogenous. However, Edelhoff and Sorensen\textsuperscript{3, 4} used the same artificial teeth from the same manufacturer, applied identical preparation parameters and assessment methods (DVA) to those used here, and still observed higher amounts of tooth structure removal. This implies that the tooth structure removal during preparation may not only be affected by the tooth morphology and the assessment method, but also by other factors such as the utilized diamond burs or the individual training of the clinician performing the preparation.

It is remarkable that regardless of the type of assessment, teeth with the lowest and the highest initial coronal volumes (maxillary right canine: 312.16 mm\textsuperscript{3}, and maxillary left molar: 620.05 mm\textsuperscript{3}) also showed the lowest and highest respective amounts of tooth structure removal. This might be explained by more complex morphology of the molars, which are potentially prepared more intensely than those with fewer surfaces and angles.

A statistically significant difference was observed among the three assessment types. The relative amount of the assessed tooth structure removal when using volumetric assessment (DVA) was significantly lower compared with weighing of milled specimens (CAMWA).

With CAMWA, digitally obtained controls and samples from DVA method were converted to physical samples through CAD-CAM milling to serve as a haptic control of the digital volumetric analyses. Milling inaccuracies may have potentially generated errors in the reproduction process resulting in significant differences between the assessment methods DVA and CAMWA. In addition, the basal portion was processed differently across DVA, WA, and CAMWA. For DVA, the basal portion was processed digitally; for WA, processing was performed manually with diamond burs fixed in a handpiece; and for CAMWA, with a
milling machine. This may also have influenced the various outcomes observed for the three analysis conditions.

The results spanning the aforementioned studies, as well as relative to this investigation, differed noticeably, despite the application of similar preparation designs. One explanation for this discrepancy may be the preparation angle, since verifying the angle during preparation is difficult even under in vitro conditions. Furthermore, the extent of tooth structure removal depends on the indication, clinician, preparation parameters, and the parameters of the diamond burs used. The diamond burs of the preparation set used here (jota kit 1424; Jota AG) were specifically designed to produce less invasive crown preparations. However, the potential influence of diamond burs on the amount of removed tooth structure is difficult to ascertain. Analyzing the influence of burs would have been possible only by preparing identical specimens with different sets of diamond burs, which should be further studied. Although the preparation parameters used in aforementioned studies were applied, the relative amount of coronal tooth structure removal was considerably lower, which may be because of the applied diamond burs in the present study.

It can also be assumed that the amount of tooth structure removal is influenced by the clinician. This factor may have a greater impact on the results than the type of assessment, specimens, or diamond burs used. To examine the influence of this factor, a multi-practitioner design of this study would have been useful. Hence, the limitation of the current study is that all preparations and examinations were made by a single investigator, and by only one type of diamond burs. There were only three different preparation designs chosen for this study: two for partial-crown and one for full-crown preparations, in four tooth morphologies of the maxilla. However, the results of this study showed that both, weight and volumetric analyses, can be applied to achieve reproducible results. The equipment used may have an impact on the results of each assessment method. The WA method’s accuracy depends on the digital scale, DVA method’s accuracy depends on the accuracy of the scanner, and the CAMWA
method’s accuracy depends on the accuracy of the scanner, the milling machine, and the digital scale.

CONCLUSION

Within the limitations of this in vitro study, it could be demonstrated that:

- The amount of tooth structure removal depends on the tooth morphology.
- The amount of the detected tooth structure removal depends on the applied assessment method. This should be taken into account when comparing tooth structure removal across studies.

ACKNOWLEDGMENTS

The authors of this study would like to thank Dr. John Lindner and Anja Mühlemann for their valuable contributions.

REFERENCES

### TABLES AND FIGURES

#### Table 1

<table>
<thead>
<tr>
<th>Tooth morphologies</th>
<th>Preparation design</th>
<th>Dimensions (mm)</th>
<th>Burs</th>
<th>Modell/Tooth morphologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>CIV</td>
<td>partial-crown</td>
<td>preparation margin 0.5</td>
<td>Jota 558.FG.013</td>
<td>Morita MD 15-500U</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Jota 558.FG.015</td>
<td>Morita SPU-500AU</td>
</tr>
<tr>
<td>CAV</td>
<td>veneer</td>
<td>mm above the cementoenamel</td>
<td>Jota 833.FGL.023</td>
<td>Morita A5H-500</td>
</tr>
<tr>
<td></td>
<td>rounded shoulder</td>
<td></td>
<td>Jota 833.FGL.023</td>
<td>Morita A5H-500-21</td>
</tr>
<tr>
<td></td>
<td>finish line</td>
<td>junction (CEJ), facial reduction of 0.8 mm</td>
<td>Jota 893F.FG.023</td>
<td>Morita A5H-500-23</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(cervical third) and 1.0 mm (middle to incisal third), incisal reduction</td>
<td></td>
<td>Morita A5H-500-26</td>
</tr>
<tr>
<td></td>
<td></td>
<td>of 1.5 mm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Preparation design and parameters for partial-crowns (veneer): CIV (maxillary right central incisor veneer), CAV (maxillary right canine veneer).
Table 2

<table>
<thead>
<tr>
<th>Tooth morphologies</th>
<th>Preparation design</th>
<th>Dimensions (mm)</th>
<th>Burs</th>
<th>Modell/Tooth morphologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>PMP</td>
<td>partial-crown</td>
<td>preparation margin 0.5 mm above the anatomical equator (AE), axial reduction of 1 mm, convergence angle of 6°, and incisal/occlusal clearance of 1.5 mm</td>
<td>Jota 558.FG.013, Jota 558.FG.015, Jota 833.FGL.023, Jota 833F.FGL.023, Jota 893F.FG.023</td>
<td>Morita MD 15-500U, Morita SPU-500AU, Morita A5H-500, Morita A5H-500-21, Morita A5H-500-23, Morita A5H-500-26</td>
</tr>
<tr>
<td>FMP</td>
<td>overlay</td>
<td></td>
<td>Jota 558.FG.013, Jota 558.FG.015, Jota 833.FGL.023, Jota 833F.FGL.023, Jota 893F.FG.023</td>
<td>Morita MD 15-500U, Morita SPU-500AU, Morita A5H-500, Morita A5H-500-21, Morita A5H-500-23, Morita A5H-500-26</td>
</tr>
<tr>
<td></td>
<td>rounded shoulder</td>
<td></td>
<td>Morita MD 15-500U, Morita SPU-500AU, Morita A5H-500, Morita A5H-500-21, Morita A5H-500-23, Morita A5H-500-26</td>
<td></td>
</tr>
<tr>
<td></td>
<td>finish line</td>
<td></td>
<td>Morita MD 15-500U, Morita SPU-500AU, Morita A5H-500, Morita A5H-500-21, Morita A5H-500-23, Morita A5H-500-26</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Preparation design and parameters for partial-crowns (overlay): PMP (maxillary left second premolar partial-crown) and FMP (maxillary left first molar partial-crown).
Table 3

<table>
<thead>
<tr>
<th>Tooth morphologies</th>
<th>Preparation design</th>
<th>Dimensions (mm)</th>
<th>Burs</th>
<th>Modell/Tooth morphologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>CI</td>
<td>full-crown margin: 0.5 incisal</td>
<td>Jota 558.FG.013</td>
<td>Morita MD 15-500U</td>
<td></td>
</tr>
<tr>
<td>CA</td>
<td>rounded shoulder from CEJ; margin</td>
<td>Jota 558.FG.015</td>
<td>Morita SPU-500AU</td>
<td></td>
</tr>
<tr>
<td>PM</td>
<td>finish line depth: 1.0; clearance: 1.5; axial convergence: 6°</td>
<td>Jota 833.FGL.023</td>
<td>Morita A5H-500</td>
<td></td>
</tr>
<tr>
<td>FM</td>
<td>occlusal/incisal</td>
<td>Jota 833F.FGL.023</td>
<td>Morita A5H-500-21</td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Preparation design and parameters for full-crowns: CI (maxillary right central incisor), CA (maxillary right canine), PM (maxillary left second premolar) and FM (maxillary left first molar).
Table 4

<table>
<thead>
<tr>
<th>Type of assessment method</th>
<th>Group 1</th>
<th>Group 2</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DVA</td>
<td>CAV</td>
<td>CIV</td>
<td>0.07</td>
</tr>
<tr>
<td>DVA</td>
<td>CAV</td>
<td>PMP</td>
<td>0.0002*</td>
</tr>
<tr>
<td>DVA</td>
<td>CAV</td>
<td>FMP</td>
<td>0.0002*</td>
</tr>
<tr>
<td>DVA</td>
<td>CIV</td>
<td>PMP</td>
<td>0.0002*</td>
</tr>
<tr>
<td>DVA</td>
<td>CIV</td>
<td>FMP</td>
<td>0.0002*</td>
</tr>
<tr>
<td>DVA</td>
<td>PM</td>
<td>FMP</td>
<td>0.001*</td>
</tr>
<tr>
<td>WA</td>
<td>CAV</td>
<td>CIV</td>
<td>0.77</td>
</tr>
<tr>
<td>WA</td>
<td>CAV</td>
<td>PMP</td>
<td>0.003*</td>
</tr>
<tr>
<td>WA</td>
<td>CAV</td>
<td>FMP</td>
<td>0.002*</td>
</tr>
<tr>
<td>WA</td>
<td>CIV</td>
<td>PMP</td>
<td>0.01*</td>
</tr>
<tr>
<td>WA</td>
<td>CIV</td>
<td>FMP</td>
<td>0.002*</td>
</tr>
<tr>
<td>WA</td>
<td>PMP</td>
<td>FMP</td>
<td>0.02*</td>
</tr>
<tr>
<td>CAMWA</td>
<td>CAV</td>
<td>CIV</td>
<td>0.77</td>
</tr>
<tr>
<td>CAMWA</td>
<td>CAV</td>
<td>PMP</td>
<td>0.006*</td>
</tr>
<tr>
<td>CAMWA</td>
<td>CAV</td>
<td>FMP</td>
<td>0.002*</td>
</tr>
<tr>
<td>CAMWA</td>
<td>CIV</td>
<td>PMP</td>
<td>0.02*</td>
</tr>
<tr>
<td>CAMWA</td>
<td>CIV</td>
<td>FMP</td>
<td>0.002*</td>
</tr>
<tr>
<td>CAMWA</td>
<td>PMP</td>
<td>FMP</td>
<td>0.01*</td>
</tr>
</tbody>
</table>

Table 4. Results of the post-hoc performed Mann-Whitney test between each pair of groups for partial-crowns: DVA (digital volumetric analysis), WA (weight analysis), CAMWA (combined computer-aided manufacture-weight analysis), CIV (maxillary right central incisor veneer), CAV (maxillary right canine veneer), PMP (maxillary left second premolar partial-crown) and FMP (maxillary left first molar partial-crown).
Table 5

<table>
<thead>
<tr>
<th>Type of assessment method</th>
<th>Group 1</th>
<th>Group 2</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DVA</td>
<td>CA</td>
<td>CI</td>
<td>1.00</td>
</tr>
<tr>
<td>DVA</td>
<td>CA</td>
<td>PM</td>
<td>0.44</td>
</tr>
<tr>
<td>DVA</td>
<td>CA</td>
<td>FM</td>
<td>0.17</td>
</tr>
<tr>
<td>DVA</td>
<td>CI</td>
<td>PM</td>
<td>1.00</td>
</tr>
<tr>
<td>DVA</td>
<td>CI</td>
<td>FM</td>
<td>1.00</td>
</tr>
<tr>
<td>DVA</td>
<td>PM</td>
<td>FM</td>
<td>1.00</td>
</tr>
<tr>
<td>WA</td>
<td>CA</td>
<td>CI</td>
<td>1.00</td>
</tr>
<tr>
<td>WA</td>
<td>CA</td>
<td>PM</td>
<td>1.00</td>
</tr>
<tr>
<td>WA</td>
<td>CA</td>
<td>FM</td>
<td>0.53</td>
</tr>
<tr>
<td>WA</td>
<td>CI</td>
<td>PM</td>
<td>1.00</td>
</tr>
<tr>
<td>WA</td>
<td>CI</td>
<td>FM</td>
<td>1.00</td>
</tr>
<tr>
<td>WA</td>
<td>PM</td>
<td>FM</td>
<td>1.00</td>
</tr>
<tr>
<td>CAMWA</td>
<td>CA</td>
<td>CI</td>
<td>1.00</td>
</tr>
<tr>
<td>CAMWA</td>
<td>CA</td>
<td>PM</td>
<td>1.00</td>
</tr>
<tr>
<td>CAMWA</td>
<td>CA</td>
<td>FM</td>
<td>0.04*</td>
</tr>
<tr>
<td>CAMWA</td>
<td>CI</td>
<td>PM</td>
<td>1.00</td>
</tr>
<tr>
<td>CAMWA</td>
<td>CI</td>
<td>FM</td>
<td>1.00</td>
</tr>
<tr>
<td>CAMWA</td>
<td>PM</td>
<td>FM</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Table 5. Results of the post-hoc performed Mann-Whitney test between each pair of groups for full-crowns: DVA (digital volumetric analysis), WA (weight analysis), CAMWA (combined computer-aided manufacture-weight analysis), CI (maxillary right central incisor), CA (maxillary right canine), PM (maxillary left second premolar) and FM (maxillary left first molar).
Figure 1. Investigated tooth morphologies: maxillary right central incisor, maxillary right canine, maxillary left second premolar and maxillary left first molar.

Figure 2. Diamond burs, specifically designed (jota kit 1424; Jota AG) for less invasive partial- and full-crown preparations.
Figure 3. Preparation parameters for maxillary right central incisor veneer (CIV), maxillary right canine veneer (CAV): margin preparation 0.5 mm above the cementoenamel junction (CEJ), facial axial wall reduction of 0.8 mm (cervical third) and 1.0 mm (middle to incisal third), incisal reduction of 1.5 mm.

Figure 4. Preparation parameters for maxillary left second premolar partial-crown (PMP), maxillary left first molar partial-crown (FMP): 0.5 mm above the anatomical equator (AE), axial reduction of 1.0 mm and incisal/occlusal clearance of 1.5 mm.
Figure 5. Preparation parameters for maxillary right central incisor full-crown (CI), maxillary right canine full-crown (CA), maxillary left second premolar full-crown (PM), and maxillary left first molar full-crown (FM): margin preparation 0.5 mm above the cementoenamel junction (CEJ), axial reduction of 1.0 mm and incisal/occlusal clearance of 1.5 mm.

Figure 6. Example of the physical control of the maxillary right canine and the physical CAD-CAM milled counter control of the maxillary right canine.
Figure 7. Prepared samples cut at cementoenamel junction (CEJ) before digital analysis (DVA) and weight analysis (WA): maxillary right central incisor veneer (CIV), maxillary right canine veneer (CAV), maxillary left second premolar partial-crown (PMP), maxillary left first molar partial-crown (FMP), maxillary right central incisor (CI), maxillary right canine (CA), maxillary left second premolar (PM) and maxillary left first molar (FM).

Figure 8. CAD-CAM samples before weight analysis (CAMWA): maxillary right central incisor veneer (CIV), maxillary right canine veneer (CAV), maxillary left second premolar partial-crown (PMP), maxillary left first molar partial-crown (FMP), maxillary right central incisor (CI), maxillary right canine (CA), maxillary left second premolar (PM) and maxillary left first molar (FM).
Figure 9. Overall relative amount of tooth structure removal combining all types of partial-crown preparations: maxillary right central incisor veneer (CIV), maxillary right canine veneer (CAV), maxillary left second premolar partial-crown (PMP), maxillary left first molar partial-crown (FMP).
Figure 10. Overall relative amount of tooth structure removal combining all types of full-crown preparations: maxillary right central incisor (CI), maxillary right canine (CA), maxillary left second premolar (PM) and maxillary left first molar (FM).

Figure 11. Overall relative amount of tooth structure removal combining all types of partial-crown preparations with regard to type of analysis: DVA = digital volumetric analysis, WA = weight analysis, CAMWA = combined computer-aided manufacture-weight analysis.
Figure 12. Overall relative amount of tooth structure removal combining all types of full-crown preparations with regard to type of analysis: DVA = digital volumetric analysis, WA = weight analysis, CAMWA = combined computer-aided manufacture-weight analysis.