Marginal accuracy and internal fit of machine-milled and cast titanium crowns

Hyun-Sook Han, DDS, MSD, Hong-So Yang, DDS, MSD, PhD, Hyun-Pil Lim, DDS, MSD, PhD, and Yeong-Joon Park, DDS, MSD, PhD
School of Dentistry, Chonnam National University, Gwang-Ju, South Korea

Statement of problem. Titanium is an alternative tooth restorative material because of its biocompatibility and mechanical properties. However, there is little information on the marginal accuracy of a complete titanium crown with different margin configurations.

Purpose. This study examined the effect of fabrication method and margin configuration on the marginal and internal fit of complete titanium crowns.

Material and methods. An acrylic resin maxillary first molar was prepared with shoulder (buccal), chamfer (palatal), and knife edge (proximal) margin configurations. Forty crowns were produced and then divided into 2 groups according to the manufacturing method (casting method or CAD/CAM technique) (n=20). Each crown was luted to the original stone die with zinc phosphate cement. The margin of the crown, center point of the axial wall, and occlusal area were measured with a 3-dimensional measuring microscope. An independent t-test (internal gap) and repeated measures 2-way ANOVA (marginal gap) were used for statistical analysis (α=.05).

Results. The mean marginal gap of the cast group was significantly smaller than that of the CAD/CAM group (P<.001). The margin configuration affected the measured marginal discrepancy (P<.001). In both groups, the mean marginal gap of the chamfer and shoulder margin was significantly smaller than that of the knife-edge margin (P<.001).

Conclusions. Castings-produced titanium crowns with a better marginal fit than the CAD/CAM technique. The knife-edge margin exhibited the greatest marginal discrepancy. (J Prosthet Dent 2011;106:191-197)

Clinical Implications
Within the limitations of this study, a chamfer margin is recommended for a complete titanium crown preparation when using both casting and milling methods.

Titanium is gaining popularity as an alternative to noble and nickel-chromium metal alloys because of its biocompatibility, low thermal conductivity, good corrosion resistance, low density, and excellent mechanical properties. In theory, the low density and high strength of titanium enable the design of more functional and comfortable prosthetic restorations. Therefore, titanium has attracted considerable interest as a restorative material for implants as well as fixed and removable dental prostheses.

Despite the many advantages of titanium, conventional casting of titanium is difficult because of its high melting point and extreme chemical reactivity at elevated temperatures. The casting temperature needed for titanium reduces oxides in the investment material by liberating oxygen atoms; this produces a reactive layer on the surface of the casting known as an alpha-case layer. In addition, it is difficult both to cast thin crown areas
in titanium and to assemble separate titanium segments by welding. To overcome these technical difficulties and achieve casting accuracy, special casting procedures have been developed. These include the use of an inert gas to create a nonreactive casting environment. In addition, crowns can be machine-milled from prefabricated titanium blocks with computer-aided design/computer-assisted manufacturing (CAD/CAM) systems. CAD/CAM techniques can be used to mill a titanium crown without forming a reactive surface layer.

The clinical success of a crown is related to the size of the marginal discrepancies. Smaller discrepancies produce less gingival irritation and dissolution of cement, thereby improving the clinical outcome and longevity of the restoration. McLean and von Fraunhofer reported that crown marginal discrepancies can range up to 120 µm after cementation and be clinically acceptable. Several studies reported that a marginal discrepancy of 120 µm can be achieved for titanium ceramic crowns. A mean marginal gap of 100 µm is considered to be within the limits of clinical acceptance.

Several authors have examined the marginal accuracy of titanium ceramic crowns. However, there is little information on the marginal fit of complete titanium crowns and their marginal configuration. This study evaluated the marginal and internal fit of complete titanium crowns depending on the fabrication method (casting and CAD/CAM technique) and marginal configuration. The null hypothesis was that the fabrication method would have no effect on the marginal accuracy and internal fit of complete titanium crowns, and that the marginal configurations would also have no effect on the marginal fit of titanium crowns.

**MATERIAL AND METHODS**

An acrylic resin analog of the right maxillary first molar (Columbia Dentoform Corp, Long Island City, NY) was prepared with a round-end diamond rotary cutting instrument (Komet diamond grinding and finishing instrument; Gebr. Brasseler GmbH & Co KG, Lemgo, Germany) and a handpiece (electric handpiece; Ney Dental Inc, Bloomsfield, Conn) mounted in a surveyor (Ney Surveyors; Ney Dental Inc). The total convergence angle was 6 degrees. An occlusal reduction of 1.5 mm was accomplished to produce a complete crown preparation. The definitive die had a 0.8 mm deep buccal shoulder finish line, a 0.5 mm deep palatal chamfer finish line, and knife edge proximal finish lines (Fig. 1). The width of each margin was controlled by keeping it no wider than half of the diamond tip used for preparation. A flat-end diamond rotary cutting instrument, 1.6 mm in diameter, at the tip (Komet 6848.314.016; Gebr. Brasseler GmbH & Co KG) was used for the shoulder margin, and a tapered diamond rotary cutting instrument, 1.2 mm in diameter at its rounded tip (Komet 6856.314.012; Gebr. Brasseler GmbH & Co KG) was used for the chamfer margin. The widths of the margins were measured with a 3-dimensional measuring microscope (Measuring microscope; Mitutoyo, Kawasaki, Japan) to determine whether the planned dimensions (0.8 mm shoulder and 0.5 mm chamfer) had been achieved. For sectioning later, 4 reference indentations were made with a low speed handpiece in the middle of the buccal, palatal, mesial, and distal root surfaces.

Forty impressions of the analog tooth were obtained from the definitive die by using a light viscosity and putty vinyl polysiloxane (Exaflex and Exafine; GC Corporation, Tokyo, Japan). Twenty impressions were selected and poured with type IV die stone (Suprastone; Kerr Lab, Orange, Calif) for casting. The remaining impressions were poured with type IV die stone (Everest Rock; KaVo Dental GmbH, Biberach, Germany) for the CAD/CAM group. The dies were kept dry for at least 2 days before further processing.

For the cast group, 2 coats of die spacer (Tru-Fit Die Relief and Visual Aid Kit; George Taub and Fusion Co, Jersey City, NJ) were applied within 1 mm of the margin with a brush system and according to the manufacturer’s instruction. The bottles were kept closed between applications, and the brush was cleaned frequently with thinner. The mean thickness of 2 coats of die spacers used in this experiment was approximately 26 µm according to a previous study.

All stone dies were sealed with a die hardener (Stone die and plaster hardener resin; George Taub and Fusion Co), and a wax separator (GC Sep; GC Corporation) was applied. Inlay wax (Green inlay, Kerr Corp, Orange, Calif) was used to produce wax patterns by using the following standardized procedure: a vinyl polysiloxane (Exafine; GC Corporation) split mold was fabricated around an acrylic resin maxillary first molar before preparation. The inner surface of a wax pattern was formed by dipping a stone die into molten wax (Dipping Bellwax,
green; Girrbach, Pforzheim, Germany). The mold was filled with molten wax and the stone die was inserted. Once the wax had cooled sufficiently, the mold was separated, and the die/crown combination was removed. The thickness of the crown was confirmed with a thickness gauge (Iwanson crown wax caliper; Surgidental instruments, Deer Park, NY). To obtain good adaptation, the pattern was melted completely through the wax over a band approximately 1 mm wide with a well-heated instrument, PKT No.1 (PKT WAXING 1; Dental USA Inc, McHenry, Ill). Wax was then added to fill the depression with a warm beavertail burnisher (Burnishers B2D; Dental USA Inc). When the pattern had cooled, the marginal excess was carved and the margin was burnished with the beavertail burnisher. The margin was examined with a stereomicroscope (Wild M1B; Leica Geosystems AG, Heerbrugg, Switzerland) at x14 magnification. Three millimeter round wax sprues were attached to the distopatal cusps, and air vents were attached near the buccal margin of the wax patterns. The vents were used to facilitate the escape of gas from the mold and promote complete mold filling during the titanium casting process. The wax patterns were invested with a Mg-based investment (Selevest CB; Selec Co, Osaka, Japan) for titanium casting at a 20mL/100g (water/powder) mixing ratio. Wax elimination was achieved by heating the mold to 850°C at 6°C/minute according to the manufacturer’s instructions. Casting with grade II commercially pure titanium (Biotan; Schütz Dental GmbH, Rosbach, Germany) was performed with a titanium casting machine (Ticast Super R; Selec Co). After casting, the investment on the crowns was removed by using airborne-particle abrasion with 50 μm aluminum oxide particles (Basic master; Renfert GmbH, Hilzingen, Germany) at a pressure of 0.3 MPa and with an ultrasonic cleaner. The casting sprues adjacent to the crown were removed by using a low speed handpiece (KaVo K9; KaVo Dental GmbH) with a separating disc (0.6 mm, No. 43135; Orbis Dental, Offenbach, Germany).

A CAD/CAM system (Everest; KaVo Dental GmbH) was used to fabricate the CAD/CAM titanium crowns. The dies and wax patterns were scanned sequentially with an optical scanner and a CAD design module (Everest scan; KaVo Dental GmbH). The simulated die spacer was programmed at 25 μm, starting 1 mm from the margin. Each titanium crown was machined from a titanium blank (Everest T-Blank; KaVo Dental GmbH) for each die with a CAD/CAM machine (Everest engine; KaVo Dental GmbH).

The base and catalyst of vinyl polysiloxane disclosing paste (Fit Checker; GC Corporation) were mixed and applied to the intaglio margin of each crown before seating on the definitive die. The crowns were seated on the corresponding dies, all excess disclosing material was removed with a gauze pad, and the material was allowed to polymerize. After removing the crown from the die, the contact spot marked by the indicator on the inside of the coping was examined visually under a stereomicroscope (Wild M1B; Leica Geosystems AG) at x14 magnification. These marked spots were removed with a tungsten carbide bur (No.H71EF; Brasseler GmbH and Co KG) with a handpiece (KaVo K9; KaVo Dental GmbH). The titanium crown and die were embedded in epoxy resin (Buehler Epoxy Resin and Hardner; Buehler, Lake Bluff, Ill) and sectioned longitudinal in the buccopalatal and mesiodistal directions with a linear precision saw (ISOMET 4000, Buehler). The sectioned surfaces were polished by consecutive grinding with #320, #800, #1200, and #2000 silicon carbide paper (SiC paper; Struers, Ballerup, Denmark). The marginal gap was estimated as the vertical marginal discrepancy according to the terminology reported by Holmes et al. (Fig. 2). At the knife-edge margin, the same definition was also used so it could be compared with the other configurations. The thickness of the cement layer on the section was measured with a 3-dimensional measuring microscope at x30 magnification (Measuring microscope; Mitutoyo, Kawasaki, Japan).
was used to determine the difference between the casting method and the CAD/CAM technique at the axial wall and the occlusal fossa area (α=.05). Repeated measures 2-way analysis of variance (ANOVA) and Bonferroni’s multiple comparison test were used to investigate the effect of the marginal configuration and the fabrication method on marginal gap (α=.05).

### RESULTS

The mean axial internal gap was 67.5 ± 20.0 µm in the cast group and 51.0 ± 10.8 µm in the CAD/CAM group, respectively. The mean occlusal internal gap was 109.8 ± 32.9 µm in the cast group and 124.6 ± 28.0 µm in the CAD/CAM group, respectively. The CAD/CAM group had significantly smaller gaps at the axial wall.

### Table I. Mean (SD) value of internal gap depending on fabrication method (Independent t-tests)

<table>
<thead>
<tr>
<th>Fabrication Method</th>
<th>Internal Gap (µm)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Axial</td>
<td>Occlusal</td>
<td></td>
</tr>
<tr>
<td>Cast</td>
<td>67.5 (20.0)</td>
<td>109.8 (32.9)</td>
<td></td>
</tr>
<tr>
<td>CAD/CAM</td>
<td>51.0 (10.8)</td>
<td>124.6 (28.0)</td>
<td></td>
</tr>
</tbody>
</table>

Different superscripted lowercase letters in column indicate significant differences (P<.05).

### Table II. Mean (SD) values of marginal discrepancy depending on fabrication method in each marginal configuration

<table>
<thead>
<tr>
<th>Fabrication Method</th>
<th>Marginal Discrepancy (µm)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shoulder</td>
<td>Chamfer</td>
<td>Knife Edge</td>
<td></td>
</tr>
<tr>
<td>Cast</td>
<td>55.2 (20.0)</td>
<td>52.2 (14.2)</td>
<td>76.1 (9.4)</td>
<td></td>
</tr>
<tr>
<td>CAD/CAM</td>
<td>67.0 (14.1)</td>
<td>59.8 (14.9)</td>
<td>80.7 (10.4)</td>
<td></td>
</tr>
</tbody>
</table>

Mean values with different superscript letter indicate that values are significantly different with respect to marginal configuration within same fabrication method group, according to Bonferroni’s multiple comparison tests (P<.05).

### Table III. Repeated-measures 2-way ANOVA results for comparison of marginal discrepancy depending on fabrication method and marginal configuration

<table>
<thead>
<tr>
<th>Source of Variance</th>
<th>df</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between-subjects</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fabrication method</td>
<td>1</td>
<td>509994</td>
<td>509994</td>
<td>3138</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Within-subjects</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marginal configuration</td>
<td>2</td>
<td>11187</td>
<td>5593</td>
<td>25</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Fabrication method × Marginal configuration</td>
<td>2</td>
<td>195</td>
<td>97</td>
<td>0.466</td>
<td>&gt;.05</td>
</tr>
</tbody>
</table>
The mean marginal discrepancies of shoulder, chamfer, and knife-edge margin configurations were 55.2 ± 20.0 µm, 52.2 ± 14.2 µm, and 76.1 ± 9.4 µm in the cast group and 67.0 ± 14.1 µm, 59.8 ± 14.9 µm, and 80.7 ± 10.4 µm in the CAD/CAM group, respectively (Table II). The ANOVA (Table III) showed that both fabrication method and marginal configuration significantly influenced the measured marginal gap (P<.001). However, the cast group had significantly smaller gaps at the occlusal area than the CAD/CAM group (P=.002) (Table I).

The mean marginal discrepancies between the cast and CAD/CAM groups, the ranking of the mean vertical marginal gap values was chamfer < shoulder < knife-edge margin. A Bonferroni’s multiple comparison test indicated a significant difference between the shoulder and knife edge margin and between the chamfer and knife-edge margin (P<.001). However, there was no significant difference between the shoulder and chamfer margin. SEM images showed better marginal fit in the cast group than in the CAD/CAM group in all margin designs (Fig. 3).

**DISCUSSION**

The data support rejection of the null hypothesis as there was a difference in the marginal and internal gap between the 2 fabrication groups and a difference in marginal discrepancy with different marginal configurations. The amount of internal and marginal discrepancy was in the clinically acceptable range of 100 µm.  

This study simulated a clinical situation by using acrylic resin tooth analogs. To standardize the measurement, a standardized fabrication of the wax pattern ensured a uniform thickness of each crown, and each
specimen was sectioned at the same position to coincide with the 4 reference indentations of the original die. To simulate the cementation of the fixed dental prosthesis clinically, the crowns were seated on a die with finger pressure.\textsuperscript{24-26} A standardized force was not used in this study to simulate the clinical situation.\textsuperscript{25}

The success of a restoration is determined by a range of factors. Marginal fit is one of the most important criteria when evaluating the clinical acceptability of the crowns. Lack of adequate fit is potentially detrimental to both the tooth and supporting periodontal tissues due to cement solubility or plaque retention. However, the descriptive terminology defining the fit varies considerably among investigators. Moreover, the same term is used for different measurements, or different terms are used for the same measurement.\textsuperscript{27} In the present study, the marginal gap was defined as the vertical marginal discrepancy according to the terminology reported by Holmes et al.\textsuperscript{27}

Two common methods of measuring the marginal gap are measurements of embedded and sectioned specimens,\textsuperscript{2,4,13} and measurements of the specimens by direct visualization.\textsuperscript{10,20} The latter method is nondestructive and provides several measuring points. However, it is difficult to obtain accurate measurements and the internal fit cannot be measured. Therefore, the former method was used in this study.

In the current study, a recognized common feature was a significantly greater occlusal internal gap than the axial and marginal ones. This is in agreement with previous studies.\textsuperscript{3,13} Also, the cast group had significantly greater internal gaps at the axial wall (Table I). This can be explained by the manual application of a die spacer in the cast titanium group dies. This study examined the options of providing accurate marginal fit of a titanium crown depending on the marginal configurations and fabrication methods. The casting technique for fabricating titanium crowns showed a better marginal fit than the CAD/CAM system. The binding of the crown and die caused by the smaller axial gap could contribute to an underseating of the CAD/CAM titanium crowns and produce a larger marginal gap. In addition, the improved castability of titanium results in a superior marginal fit of the cast titanium crowns.\textsuperscript{6,7}

Both in the cast group and the CAD/CAM group, the mean marginal gap at the chamfer margin was within the range of the values reported by previous studies.\textsuperscript{3,10,18,20} Depending on the marginal configurations, the chamfer margin demonstrated the least marginal discrepancy, followed by the shoulder and knife edge margin in that order. However, the difference between the chamfer and shoulder margin was not statistically significant. In the knife edge margin, the vertical marginal discrepancies were largely due to factors that cause distortion during fabrication (Table II).

There were some limitations in this study. Although finger pressure is often used clinically to lute restorations, the force used to seat the restorations was not standardized. The use of a loading apparatus would provide a more uniform load on all the specimens. In this study, the marginal accuracy measurements depended on stone dies to simulate the configuration of teeth prepared to receive the complete crowns. The use of the stone or epoxy resin dies to measure the marginal discrepancy is an accepted procedure.\textsuperscript{13,24} However, the use of human teeth would be the ideal for simulating a clinical procedure. The limitations of this study include measurement of only the vertical marginal discrepancies. The horizontal relationship was not quantified.

In this study, the marginal adaptability of a cast titanium crown and CAD/CAM titanium crown was acceptable clinically but worse than that of a noble metal, particularly with the CAD/CAM titanium crown.\textsuperscript{20} However, continued research and clinical applications of single crowns and fixed dental prostheses are needed to improve the use of titanium as an alternative restoration material. Improvements in CAD/CAM technology for titanium are needed.

### CONCLUSIONS

Within the limitations of this study, cast titanium crowns had significantly smaller discrepancies at the occlusal area than CAD/CAM titanium crowns. With regard to the marginal accuracy, the casting method showed a better marginal fit for fabricating complete titanium crowns than the CAD/CAM technique. The chamfer and shoulder margin had smaller marginal gaps than the knife-edge margin in both the casting method and the CAD/CAM technique. The measured marginal discrepancy of the complete titanium crowns fabricated with both methods demonstrated a clinically acceptable range of 100 \textmu m in this in vitro study.

### REFERENCES

Fatigue of zirconia and dental bridge geometry: Design implications


Zirconia is currently used as a framework material for posterior all-ceramic bridges. While the majority of research efforts have focused on the microstructure and corresponding mechanical properties of this material, clinical fractures appear to be largely associated with the appliance geometry.

Objective. The objective of this study was to estimate the maximum stress concentration posed by the connector geometry and to provide adjusted estimates of the minimum connector diameter that is required for achieving 20 years of function.

Methods. A simple quantitative description of the connector geometry in an all-ceramic 4-unit bridge design is used with published stress concentration factor charts to estimate the degree of stress concentration and the maximum stress.

Results. The magnitude of stress concentration estimated for clinically relevant connector geometries ranges from 2 to 3. Using previously published recommendations for connector designs, adjusted estimates for the minimum connector diameter required to achieve 20 years of clinical function are presented.

Significance. To prevent clinical fractures the minimum connector diameter in multi-unit bridges designs must account for the loads incurred during function and the extent of stress concentration posed by the connector geometry.

Reprinted with permission by the Academy of Dental Materials


Corresponding author:
Dr Hong-So Yang
Department of Prosthodontics
School of Dentistry
Chonnam National University
Yongbong-ro 77, Buk-gu
Gwangju 500-757
SOUTH KOREA
Fax: +82-62-530-0130
E-mail: yldsdent@jnu.ac.kr


Noteworthy Abstracts of the Current Literature