Influence of various gypsum materials on precision of fit of CAD/CAM-fabricated zirconia copings

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The clinical applicability of CAD/CAM-fabricated zirconia copings is tested using working models made from four different high-strength Type IV gypsum materials. Each of the four materials was used to fabricate 15 zirconia copings. Precision of fit was measured with a digital electron microscope using the silicone replica technique. The mean and standard deviation of each reference point were analyzed using the one-way analysis of the variance (ANOVA) and Tukey’s honest significant difference (HSD) tests (α=0.05). The overall marginal and internal fits of the zirconia copings were as follows: GS (GS: Grey Stone) group: 91.43 μm, LS (LS: Light green Stone) Group: 87.89 μm, RS (RS: Red Stone) Group: 88.75 μm, BS (BS: Beige Stone) Group: 82.78 μm. There were no significant differences between the mean adaptations of the gypsum varieties (p>0.05). This confirmed that the type of gypsum material used does not determine the precision of fit of a prosthesis.

Keywords: Dental CAD/CAM, Fit, Type IV gypsum, Zirconia coping

INTRODUCTION

The formation of accurate impressions of patients’ oral environments and fabrication of models from gypsum that accurately reproduce the relationship between an abutment and teeth are two of the most important topics in prosthesis manufacturing9. In order to create an accurate working model, the clinician must be fully aware of the physical properties presented during the curing reaction as well as the effects of post-curing on the mechanical and chemical characteristics. Moreover, the clinician must select a gypsum material that can compensate for shrinkage. Also, the gypsum material used for the fabrication of the model must not only be simple to use, but also possess minimum porosity20.

At present, gypsum materials for clinical use are categorized into Types I through V as per No. 6873 of the International Standard Organization (ISO). Type I is a dental plaster for impressions. Type II is a dental plaster for fabricating models. Type III is a dental stone for creating models. Type IV is a low-expansion, high-strength dental stone for fabricating models and dies. Type V is a high-expansion, high-strength dental stone for fabricating models and dies. To produce a precise model and die, both minimal expansion during hardening and strength must be excellent9. In particular, Type IV stone shows relatively less expansion during hardening compared to Type V stone and is the most commonly used gypsum in dies and models, consistent with the American Dental Association (ADA) specification No. 25.

One of the most important requirements for the fabrication of an accurate dental stone prosthesis is the accurate replication of the anatomical conditions of the patient’s oral environment. According to ADA specification No. 25, gypsum can expand as much as 0.2%, thus significantly influencing the degree of displacement in the working model8. Furthermore, a gypsum model that creates a full arch is relatively small, but it must demonstrate volumetric stability and reproducibility. As such, the selection of an appropriate type of gypsum is of the utmost importance. In order to prepare a precise prosthesis after studying an oral environment, one must first fabricate an accurate working model10.

Gypsum materials for various purposes are sold. Although the ISO has investigated the physical and chemical properties of gypsum materials, detailed and substantive studies of their clinical applicability are somewhat lacking. In particular, although the frequency of prosthesis creation by means of CAD/CAM has increased, there have not been enough studies into the suitability of various gypsum materials for CAD/CAM prosthesis fabrication. Previous studies have examined the influence of the properties of dental materials on the CAD process. A study by Delong et al.9 reported that contactless scanners are influenced by the color, transparency, and surface texture of the scanned object when creating a 3D digital model. Rodriguez et al.7 also reported that the quality and precision of 3D digital models are influenced by the color and transparency of the materials used for castings and impressions. However, the above studies only examined the precision and resolution of 3D digital models and failed to discuss their influence on the final dental prostheses used by...
patients.

After a working model is fabricated from gypsum, a 3D digital model is acquired via a scanning process using a 3D dental scanner. The 3D digital model can then be used to examine the patient and design an appropriate prosthesis using commercial software. Not only is such a 3D digital model not constrained by time or location, it can also be shared among many people by copying the data and sending it via e-mail, thus protecting it against loss. Despite these advantages, if the resolution or precision of a 3D digital model is insufficient, its use will be restricted. Because 3D digital models are the foundation for designing suitable prostheses for patients, precision and reproducibility are essential. The accuracy of a prosthesis is dependent on the dental impressions taken from the patient. As such, it is self-evident that the accuracies of 3D digital models and working models affect the accuracies of prostheses. Also, the precision of fit of CAD/CAM-fabricated dental prostheses has been reported to be influenced by the input data concerning abutments. Therefore, it is considered to be significant to comparatively evaluate the clinical applicability of various types of gypsum materials with respect to their influences on the precision of fit of final prostheses.

Consequently, the present study investigates the influences of various gypsum materials on the precision of fit of CAD/CAM-fabricated prostheses. To this end, four types of high-strength gypsum that are widely used in clinical dental settings were selected and working models were fabricated from those materials. Afterwards, dental prostheses were fabricated using CAD/CAM, based on the working gypsum models and their marginal and internal fits were evaluated. We attempted, thus, to investigate the influences of different types of gypsum materials on the precision of fit of dental prostheses and to evaluate them comparatively based on clinically acceptable thresholds to produce reference data for future clinical applications.

MATERIALS AND METHODS

Production of the titanium master cast

For these experiments, the maxillary right first molar was selected as the abutment. In order to fabricate a master model, the abutment was prepared after selecting a standard full arch model fabricated from resin (AG-3, Frasaco GmbH, Tettnang, Germany). On the basis of the thickness and marginal shape of the zirconia coping, the abutment was designed using the recommended specifications of the Lava™ software. The tooth was subjected to a mean axial wall taper of 5° at the margin and rounded slope of the chamfer. In addition, the tooth was subjected to a 1 mm offset at the axial surface and 1.2 mm offsets at the occlusal and incisal surfaces. Using the digital abutment model as a reference, the master model was fabricated by means of titanium machining (Fig. 1).

Manufacturing of working models

In order to create the working model, the master model was replicated into 60 impression molds using a silicone impression material (Deguform, DeguDent, Germany). After applying a wetting agent (Picosilk®, Renfert, Hilzingen, Germany) onto the 60 duplicate casts, four different kinds of commonly used Type IV gypsum were each used to produce 15 working models, giving a total of 60 working models (Table 1 and Fig. 2).

Production of zirconia copings using the Lava™ system

The first step in constructing the zirconia copings was to prepare digital impressions by scanning the 60 working models with a laser scanner (Lava™ Scanner, 3M ESPE, Seefeld, Germany). The second step was to use the requisite CAD program on the scanned digital impressions to design the zirconia copings. Once the designs were complete, the files were sent to a milling machine (Lava™ Milling unit, 3M ESPE) to manufacture the pre-sintered zirconia blocks (Lava™ Zirconia Frame, 3M ESPE). The resulting zirconia copings were fully sintered in a furnace (Lava™ Therm Furnace, 3M ESPE). The final 60 zirconia copings were then tested by fitting them onto their respective cast abutments. 20 μm of internal cement space was allotted, as per the traditional method; an experienced dental lab technician performed the internal adjustments.

Definition of fit and measurement of silicone replica

In measuring the marginal and internal fits, defining the precision of fit is very important. The studies of Werrstein et al. and Borba et al. employed the definition used by Lee et al. As per the aforementioned definition, the points selected to compare the marginal and internal fits were the buccal and lingual margins (1, 6), buccal and lingual axial walls (2, 5), and the centers of the buccal and lingual inclines on the occlusal surface (3, 4) (Fig. 3). The marginal and internal fits were measured using the silicone replica technique. This is a method that measures the internal space between the dental prosthesis and the abutment tooth by replicating the space with silicone and measuring.

Fig. 1  Titanium abutment model.
Fig. 2 The different gypsum materials used in the fabrication of the abutment models.

Table 1 Materials used

<table>
<thead>
<tr>
<th>Group</th>
<th>Brand name</th>
<th>Color</th>
<th>Manufacturer</th>
<th>Lot. number</th>
</tr>
</thead>
<tbody>
<tr>
<td>GS</td>
<td>Tuff rock</td>
<td>Gray</td>
<td>Talladium INC, Valencia, USA</td>
<td>#5110009</td>
</tr>
<tr>
<td>LS</td>
<td>Die keen</td>
<td>Light green</td>
<td>Heraus Kulzer INC, NY, USA</td>
<td>#9812376</td>
</tr>
<tr>
<td>RS</td>
<td>MG crystal rock</td>
<td>Red</td>
<td>Maruishi Gypsum, Tokyo, Japan</td>
<td>#51220303</td>
</tr>
<tr>
<td>BS</td>
<td>GC Fujirock EP</td>
<td>Beige</td>
<td>GC Corp, Tokyo, Japan</td>
<td>#J0228902201</td>
</tr>
</tbody>
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the silicone thickness. The reliability and accuracy of the method have been verified in previous studies. After filling the completed zirconia coping with light body silicone, the coping was immediately placed onto a stone die and held in place with finger pressure. In order to maintain a constant force of 50 N, an electric scale was used. The cured light body silicone (Aquasil Ultra XLV; Dentsply Caulk, Milford, USA) was then carefully separated from the coping. The resulting light body silicone film represented the space between the coping and the die. Since it exhibited very little resistance to tearing and its structural integrity was difficult to maintain, a stronger heavy body silicone (Aquasil Ultra Monophase; Dentsply Caulk, Milford, USA) was also applied to stabilize the silicone film.

Uniform cutting can be difficult because the light body silicone was additionally covered by the heavy body silicone in a separate tray. The separate tray was made in a form of a square box of baseplate wax with the same length, width and height of 30 mm, respectively. To guarantee the accurate uniform cutting of all the specimens, the completed silicone replica was segmented by a razor blade at the exact center in the medial, distal, buccal, and lingual directions using a ruler (Fig. 4). In order to increase the reliability of measurements, the six points of fit were measured five times and their average values were taken. Silicone thicknesses were observed using a digital microscope with a 160× objective lens (KH-7700; Hirox, Tokyo, Japan) (Fig. 5).

Statistical analysis

Statistical analysis was carried out using SPSS 20.0 for Windows (SPSS Inc., Chicago, IL, USA). Using an electron microscope, the marginal and internal adaptations were determined and the mean and standard deviations of the respective experimental groups were computed from a total of 60 samples. In order to identify the normal distribution of the measured values, the Shapiro-Wilk test was performed. The test yielded a p value result of 0.153 (p>0.05), verifying a normal distribution of the measurements. Based on the results of the normality and parametric tests, a one-way analysis of the variance (ANOVA) was performed. Afterwards, Tukey's honest significant difference (HSD) test was also performed. The significance level of the experiment was set to 0.05.

RESULTS

The mean±SD of the precision of fit of the zirconia copings fabricated from the four different Type IV gypsum abutment models are presented in Table 2. The GS group exhibited the greatest variation for all reference points, while the BS group exhibited the smallest variation, thus demonstrating its superior fit. With regards to the mean values of the six reference points measured for each of the four groups, the results
exhibited no significant differences \((p>0.05)\). As a result of measuring the overall mean±SD from the sum of all six reference points, the GS, LS, RS, and BS groups were found to exhibit mean±SD values of 91.43±17.21 μm, 87.89±19.87 μm, 88.75±16.22 μm, and 82.78±18.51 μm, respectively. Comparing the four groups did not yield statistically significant differences (Table 2).

After the mean values of each of the six reference points were compared, the points themselves were grouped into the marginal area (1, 6), axial wall area (2, 5), and occlusal area (3, 4) and again compared. The mean±SD results of the comparison between these groups are presented in Table 3. The GS group exhibited the largest variation of all of the groups, while the BS...
group exhibited the smallest variation. Comparing the means±SD results of the four groups did not show statistically significant differences (p>0.05) (Table 3).

**DISCUSSION**

In the present study, gypsum abutment CAD/CAM models were fabricated using four different kinds of Type IV gypsum materials and zirconia coping. The qualities of the final prostheses were evaluated based on precision of fit standards and the clinically acceptable threshold value was evaluated. By comparing the fits of each experimental group as presented in Table 2, it was found that none of the experimental groups exhibited significantly different precision of fit (p>0.05). Also, after comparing the precision of fit by grouping the reference points into the margin area (1, 6), axial wall area (2, 5), and occlusal area (3, 4), no statistically significant difference (p>0.05) was observed among the experimental groups. The results of this study did not show any significant difference between the three groups (LS, RS, and GS) in the mean marginal and internal fit of the zirconia coping containing Type IV gypsum. The GS group showed the worst fit and the BS group the best fit of the three groups (LS, RS, and GS); however, the differences were negligible.

During the CAD/CAM stage of the prosthesis fabrication process, the possibility of increasing marginal and internal discrepancies is present at every step. The first point at which this can occur is during 3D data input, when working with the scanner. Laser scanners in particular can cause additional errors due to reflective coatings, the input process, and debugging. Any defects in the milling machine, as well as mechanical wear and tear, including the displacement of diamonds in the diamond milling machine, can also cause marginal and internal discrepancies. CAM vibrations and rotating shaft instability during the milling process can contribute to errors. While metal-cutting milling machines have a continuous blade with a smooth surface, the porcelain-cutting diamond milling machine used has a cutting blade with a rough surface such that the sharp edges of the margin can shatter and, thus, increase the marginal gap. Furthermore, CAM permits the simultaneous milling of as many as 5 axes. As such, the internal surface is subject to milling first and then, after rotating the milled object by 180°, the external surface is subject to milling. At this time, either the x or y-axis must be set back to its original position and if proper positioning does not occur, errors will ensue. However, from our results, we cannot conclude that the type of gypsum used to transform the gypsum abutment model to the 3D digital model in the CAD process has a large influence on marginal or internal discrepancies.

Although there have been many clinical applications of CAD/CAM zirconia copings, the increasing use of zirconia copings must be met with the corresponding evaluation of the performance of such clinical applications. Of the many standards used to evaluate clinical applications of prostheses, marginal and internal adaptations are important factors to consider. If the marginal adaptation is poor, the prosthesis can cause periodontal diseases and dental caries. Marginal maladaptation can also result in the complete displacement of the prosthesis. For example, if the internal gap is too large, then there can be problems with stability, as this characteristic of the prosthesis is almost entirely dependent on the cement used rather than tooth formation. As such, the application of a marginally maladapted prosthesis can result in the loss of proper orientation. On the other hand, if the internal gap is too small, the prosthesis will be mounted imperfectly and, thus, its stability will be compromised. Thus far, many researchers have attempted to establish marginal and internal space standards for dental prostheses, through theoretical and experimental work. Sorensen et al. claimed that to inhibit bone loss resulting from marginal errors, marginal spaces must be smaller than 50 μm. McLean and von Fraunhofer reported that a marginal gap of less than 80 μm cannot be radiologically distinguished and a probe with a diameter of 80 μm cannot distinguish a gap of 200 μm. In a study that investigated 1,000 prostheses that had been mounted in oral environments for at least five years, marginal discrepancies of approximately 100 μm were found to rarely create clinical problems. In addition, the clinically acceptable maximum marginal gap was determined to be 120 μm. There have also been studies of the marginal adaptations of prostheses fabricated with CAD/CAM. May et al. used the Procura ® software to report that the marginal and internal gaps of Procura ® copings are smaller than 70 μm. Hertlein et al. reported that the marginal gaps obtained using the Lavi ® software were 38±20 μm and that absolute marginal error was 72±36 μm.

With respect to internal gap standards, Bindl and Mommack evaluated the fit of CAD/CAM-fabricated zirconia cores with chamfer margins and found that they produced internal mid-mesiodistal gap widths of 82±49 μm and internal mid-buccolingual gap widths of 114±58 μm. Beuer et al. reported that the CEREC ® software yielded a minimum gap value of 57.4 μm and a maximum of 125.5 μm while Kunii et al. reported that the KATANA ® software yielded gaps of 101.7±9.5 μm. The values for the precision of fit of the zirconia copings measured in the present study were 91.43±17.21 μm, 87.89±19.87 μm, 88.75±16.22 μm, and 82.78±18.51 μm, thus demonstrating little difference among the experimental groups. None of the experimental values exceeded the clinically acceptable threshold of 120 μm proposed by McLean and von Fraunhofer. The present study also did not produce results different from those of Hertlein et al. It is thus confirmed that the type of dental casting material used does not have a defining impact on the clinical acceptability of the quality of fit of a dental prosthesis.

In the present study, CAD/CAM-fabricated zirconia copings exhibited clinically acceptable levels of marginal and internal adaptability and uniform surfaces. However, considering that sample numbers were small...
and measurement results were based on an in vitro standard model, further research must be conducted to realize general clinical application. Also, because each study has different definitions and terminologies for precision of fit reference points, basing a conclusion solely on the study of marginal and internal fits may be insufficient. Furthermore, the results of this study can be generalized to only a limited degree because the internal surface of zirconia copings made using a CAD/CAM system is adjusted by a dental laboratory technician. That is, depending on the proficiency of the technician, the results may vary. In this study, this limitation was recognized, but to reflect the actual clinical situation, adjustments by the dental laboratory technicians were not disallowed. Future studies can minimize this potential error by prohibiting internal surface adjustment, allowing a more objective conclusion to be drawn. As such, in order to fabricate prostheses with superior aesthetics and fits, more detailed investigations of complex core designs, milling precision, and plasticity and cementation of dentin and enamel porcelain are necessary.

CONCLUSIONS

The present study fabricated working models from four different kinds of commercial Type IV gypsum materials. Zirconia copings were then created based on data provided by 3D digital models constructed using a dental scanner. The precision of fit of the prostheses manufactured from the respective working casts were evaluated by measuring their marginal and internal fits. Within the limited scope of this study, the following results were obtained. No significant differences were observed between the fits of zirconia copings fabricated from different kinds of Type IV gypsum materials. The marginal and internal fits of the working models also did not exhibit any statistically significant differences (p>0.05). In conclusion, all four kinds of gypsum material demonstrated similar fits with respect to the fabricated zirconia coping.

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REFERENCES