Evaluation of Marginal and Internal Gaps of Metal Ceramic Crowns obtained from Conventional Impressions and Casting Techniques with those obtained from Digital Techniques

Abstract

Background: Accuracy in fit of cast metal restoration has always remained as one of the primary factors in determining the success of the restoration. A well-fitting restoration needs to be accurate both along its margin and with regard to its internal surface. Aim: The aim of the study is to evaluate the marginal fit of metal ceramic crowns obtained by conventional inlay casting wax pattern using conventional impression with the metal ceramic crowns obtained by computer-aided design and computer-aided manufacturing (CAD/CAM) technique using direct and indirect optical scanning. Materials and Methods: This in vitro study on preformed custom-made stainless steel models with former assembly that resembles prepared tooth surfaces of standardized dimensions comprised three groups: the first group included ten samples of metal ceramic crowns fabricated with conventional technique, the second group included CAD/CAM-milled direct metal laser sintering (DMLS) crowns using indirect scanning, and the third group included DMLS crowns fabricated by direct scanning of the stainless steel model. The vertical marginal gap and the internal gap were evaluated with the stereomicroscope (Zoomstar 4); post hoc Turkey’s test was used for statistical analysis. One-way analysis of variance method was used to compare the mean values. Results and Conclusion: Metal ceramic crowns obtained from direct optical scanning showed the least marginal and internal gap when compared to the castings obtained from inlay casting wax and indirect optical scanning. Indirect and direct optical scanning had yielded results within clinically acceptable range.

Keywords: Computer-aided design and computer-aided manufacturing, metal ceramic crowns, optical scanning

Introduction

Accuracy in fit of cast metal restoration has always remained as one of the primary factors in determining success of the restoration. A well-fitting restoration needs to be accurate both along its margins and with regard to its internal surface.[1]

Studies in the literature have revealed that gingival tissue adjacent to the margin of an artificial crown contains chronic inflammatory infiltrate and this infiltrate is believed to have occurred due to accumulation of bacterial plaque at microscopic opening of margins of the restoration.[2] Poor internal fit of a coping can increase the thickness of the cement and thus influence the mechanical stability of dental restorations. The minimization of crown marginal gap and internal gap is an important goal in prosthodontics. Based on literature review, ideal marginal gap is 25–40 µm. According to McLean, the acceptable vertical marginal gap ranges between 120 µm,[3] ideal internal gap ranges between 20 µm and 40 µm, and internal gap ranges between 50 µm and 100 µm.[4]

In general, marginal gap and internal gap of restorations are very much influenced by clinical and laboratory factors. Clinical factors include geometry of tooth[5] preparation, type of finish line and degree of taper, impression materials, and cement used to lute the restoration in dental office.[6] Laboratory factors that affect marginal gap and internal gap are incompatibility of dental materials such as wax, die stone and casting investments, die spacer, and the casting techniques.

The fabrication of dental cast restorations with the base metal alloys by lost wax technique involves impression procedure, preparation of the die, fabrication of...
pattern, and investing and casting. Difficulties encountered during casting of base metal dental alloys limit their use. Application of these alloys might be enhanced if casting procedure is completely eliminated and new techniques are used. One of the new techniques for fabrication of alloy copings reported in the literature is direct metal laser sintering (DMLS).

DMLS is a new technique that replaces conventional metal casting procedures. DMLS is a computer-aided design and computer-aided manufacturing (CAD/CAM)-based technique in which frame works and metal copings can be designed and fabricated using cobalt-chromium (Co-Cr). Co-Cr powdered alloy used in this technique has slight variations in composition. The molybdenum content in the alloy powder used in DMLS is comparatively less than the alloy which is used for conventional casting. A high power laser beam is focused onto a bed of powdered metal (Co-Cr), these areas fuse into thin solid layer and another layer of powder is then laid down over this and the next slice of framework is produced and fused with the first until framework or coping is finished.

The CAD/CAM process of producing copings by DMLS technique using automated scanning process and powerful computer-aided design software offers many advantages such as complete control over the framework and coping designing, margin placement, cement space maintenance, coping thickness, and pontic designs, as well as elimination of casting procedures.

Aim of the study

1. To evaluate vertical marginal and internal gap of metal ceramic crowns obtained by conventional inlay casting wax pattern using conventional impression
2. To evaluate vertical marginal and internal gap of metal ceramic crowns obtained by CAD/CAM technique using conventional impression by indirect optical scanning
3. To evaluate vertical marginal and internal gap of metal ceramic crowns obtained by CAD/CAM technique using direct optical scanning
4. To comparatively evaluate the vertical marginal and internal gap of metal ceramic crowns obtained from inlay casting wax pattern and crowns from CAD/CAM technique using conventional impression and crowns from CAD/CAM technique using indirect and direct optical scanning.

Materials and Methods

A custom-made stainless steel master model was prepared simulating the shape and dimension of a prepared tooth resembling the first molar using a computer numerical control milling machine.

The sample is prepared to the shape and dimension of a prepared tooth resembling a maxillary first molar of 8 mm in cervical diameter, 7 mm in height, axial reduction of 1.2 mm, rounded axial line angles, 10° occlusal surface inclination, 135° chamfer finish line, and an occlusal bevel resembling functional cusp bevel of 45° [Figure 1]. The first cylindrical section (C1) of the metal die was contiguous to tooth preparation finish line. The cylindrical section was 10 mm in height and 8 mm in diameter. The octagonal section (C2) was 8.3 mm in height and 13 mm in diameter. External surface of (C2) cylindrical section was equally divided into eight parts, which helps in placement of master model on the platform of the stereomicroscope. A custom-made stainless steel former was fabricated, such that the former could be accurately positioned over the stainless steel die. The stainless steel former was larger than the die in all dimensions by 0.5 mm uniformly [Figure 2]. This was done to maintain a space of 0.5 mm throughout between the die and the former. This space helped obtain the pattern copings with uniform thickness. The counterpart also had three vertical slits which acts as escape hole for the excess molten inlay casting wax that comes out during assembling of master die to the metal counterpart.

An elastomeric impression of the custom-made stainless steel model was made using addition silicone (Aquasil, Dentsply) using two-stage technique. Type IV dental stone was mixed in w/p ratio as recommended by the manufacturer. The mixed die stone material was poured into the mold. The master die was treated with die hardener and 3 coats of die spacer (YETI, Germany) to create 30 µ space, simulating the luting cement space. Die lubricant (YETI, Germany) was applied onto the die and the fitting surface of the stainless steel former. The inlay casting wax (GC Corporation, Tokyo, Japan) was melted and painted on the type IV die. The master die and stainless steel die former assembly was held together for 1 min with finger pressure. The stainless steel former helps in obtaining a uniform wax pattern thickness of 0.5 mm.

Sprue was attached to the patterns and was invested. Burnout procedure and casting were performed in the regular conventional way following the manufacturers’ instructions.

![Figure 1: Stainless steel model and model former axial and occlusal view](image)
Fabrication of direct metal laser sintering coping using indirect optical scanning

The type IV die stone master die is scanned using D700 three-dimensional scanner which guarantees superior scanning results. The scanner employs two cameras and three-axis motion system, which results in accuracy of the object geometry acquisition. The 3-axis allows the object to be tilted, rotated, and translated so as to be scanned from any viewpoint, making 3-axis the optimal number of axis for a scanning volume corresponding to a dental model. The desired spacer thickness of 30 µm is programmed 1 mm short to the margin. The nonuniform offsetting and shelling algorithm is proposed to create the coping shell model with uniform thickness of 0.5 mm. The stereolithography (STL) data thus obtained are forwarded to computer-aided manufacturing (CAM) bridge, which is a professional software for automatic part placement. From here, the data are forwarded to building chamber where infrared laser beam is used to fuse the (Co-Cr) powder, layer by layer to produce the solid object. Production begins once a layer of powder is spread across the build platform, which is then evenly spread with a powder leveling roller. The laser beam scans the powder surface heats the particles and fuses them. After the first layer solidifies, the built platform moves another layer of powder, which is again sintered by the laser beam. The process is repeated until the coping is completed [Figure 3].

Fabrication of direct metal laser sintering copings using direct optical scanning

The master metal die is scanned using Sirona intraoral scanner which guarantees superior scan. The STL data thus obtained are forwarded to CAM bridge. Then, the fabrication of DMLS copings was processed similar to that of Group (G2) [Figure 4].

Cementation of the porcelain-fused-to-metal crowns on master model

All thirty test samples were applied with a thin layer of pressure-indicating paste and cemented on the stainless steel die and a load of 2 kg is applied for 2 min, with metal ceramic crowns against the vertical axis of the tooth preparation section using a surveyor. The 2 kg load was placed over a custom made metal platform which had a slot in the center to engage the vertical arm of the surveyor [Figure 5]. This same procedure was followed for applying load for all the thirty test samples. This was done to simulate a coping cemented in the oral condition. Pressure-indicating paste was used for cementing purpose as it was easy for retrieval of the copings from the model without any damage to the coping and the master model. The vertical marginal discrepancy was determined as the maximum distance between the tooth preparation margin and the most apical part of the casting margin in a plane parallel to the long axis of the tooth preparation.

Measurement of vertical and marginal gaps

All the thirty test samples of groups G1, G2, and G3 were evaluated for vertical marginal gap and internal gap employing Stereomicroscope in microns. The vertical
marginal gap at the margin of the casting and the die was measured using stereomicroscope [Figure 6a]. Marginal gap was measured to the nearest micron on each cast coping at the eight predetermined reference areas on the stainless steel master model separated by 45° [Figure 6b]. For each sample, the mean vertical marginal gap was obtained and the overall mean vertical marginal gap for that test group was obtained from these means. The results thus obtained were statistically analyzed [Table 1].

**Measurement of internal gaps for G1, G2, and G3**

The internal gap was evaluated after cementation of the copings using pressure-indicating paste. The luted crowns are retrieved along with the pressure-indicating paste after 10 min. The heavy body is injected on to the internal surface of the crown with pressure-indicating paste. The heavy body along with pressure-indicating paste was retrieved as a single block and heavy body is again injected on to the external surface of the crown surface of the pressure-indicating paste. Moreover, the blocks are sectioned into three pieces with two slices, namely, slice a and slice b and measurements are made at 18 points [Figure 7a].

The internal gap between the inner surface of the heavy body and the external surface of the heavy body with pressure-indicating paste was measured, using stereomicroscope [Figure 7b]. The measurements thus obtained were tabulated. For each sample, the mean internal gap was obtained and the overall mean internal gap for that test group was obtained from these means. The results thus obtained were statistically analyzed [Tables 2 and 3].

All statistical calculations were performed using Microsoft Excel (Microsoft, USA). Post hoc Tukey’s test was used for statistical analysis. One-way analysis of variance (ANOVA) method was used to compare the mean values, standard deviation, $F$ value, and $P$ value of each test group, and $P < 0.05$ was considered statistically significant.

**Results**

**Inference**

Table 4 shows the comparison of mean values of the vertical marginal gap obtained for each of the three groups. One-way ANOVA test was used to calculate the “$F$” value. Since the $P < 0.05$, there is a significant difference between three groups with regard to vertical marginal gap. Multiple
range test by *post hoc* Tukey’s test was employed to identify significant groups at 5% level. The mean vertical gap was statistically significant from each other. Group 3 showed least mean vertical marginal gap followed by Groups 2 and 1.

**Inference**

Tables 5 and 6 show the comparison of mean value of the internal gap obtained for each of the three groups. One-way ANOVA was used to calculate the “*P*” value. Since the *P* < 0.05, there is a significant difference between the three groups with regard to internal gap. Multiple range test by *post hoc* Tukey’s test was employed to identify significant groups at 5% level. Group 3 showed least mean internal gap. The mean internal gap was statistically significant from each other. Group 3 showed least mean vertical marginal gap followed by Groups 2 and 1.

**Discussion**

There are many clinical and laboratory factors responsible for the marginal and internal adaptation of dental cast restorations.[18,19] Technical errors such as damage to the margins during die trimming, excessive thickness of die spacer, inaccurate wax adaptation, incorrect investments, and casting failures may occur. To minimize marginal and internal fit inaccuracies, the following methods and technique have been advocated by various authors:[17,20,21] overwaxing the margin of wax pattern, removing wax from internal surface of wax pattern,[22] die relief with application of die spacer, internal relief of cast restoration by sandblasting, mechanical milling, acid etching, electrochemical milling, and occlusal venting for escape of restoration.[7,8,23,24]

In DMLS technique, Co-Cr powdered alloy is used in composition. The molybdenum content in the alloy powder used in DMLS is comparatively less than the alloy which is used for conventional casting. This new technique produces high accuracy, detailed resolution, good surface quality, and excellent mechanical properties.[25-32]

The basic data obtained in this study showed the mean vertical marginal gap of 122.55 µm for metal ceramic crowns obtained from inlay casting wax patterns (G1), 72.68 µm for metal ceramic crowns obtained from indirect optical scanning of the master die (G2), and 36.38 µm for metal ceramic crowns obtained from direct optical scanning of the metal die (G3). This study was in congruence with Baig et al.[33,34] who concluded that after casting, marginal gap ranged from 40 µm to 61.5 µm with a marginal gap of 120 µm which is the maximum clinical acceptable gap.[35] Similarly, Dedmon[10] stated that mean un-cemented marginal openings were 105 and 95 µm for vertical and horizontal openings, respectively.

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**Table 4: Test of significance for the mean vertical marginal gap obtained from three groups (Group 1, Group 2, and Group 3)**

| Descriptive statistics of marginal fit | Sample number | Minimum | Maximum | Mean | SD | *P* |
|---------------------------------------|---------------|---------|---------|------|----|-----|
| Group 1                               | 10            | 110.15  | 130.74  | 122.55 | 6.29 | 0.001 |
| Group 2                               | 10            | 70.40   | 77.02   | 72.68  | 2.26 |      |
| Group 3                               | 10            | 31.90   | 40.11   | 36.38  | 2.66 |      |

SD=Standard deviation

**Table 5: Test of significance for the mean internal gap on occlusal surfaces from three groups (Group 1, Group 2, and Group 3)**

| Descriptive statistics of internal fit on occlusal surfaces | Sample number | Minimum | Maximum | Mean | SD | *F* | *P* |
|------------------------------------------------------------|---------------|---------|---------|------|----|-----|-----|
| Group 1                                                    | 10            | 277.47  | 351.46  | 319.67 | 20.02 | 488.33 | 0.001 |
| Group 2                                                    | 10            | 197.73  | 208.75  | 202.6 | 3.64 |     |     |
| Group 3                                                    | 10            | 147.72  | 163.33  | 155.86 | 4.82 |     |     |

SD=Standard deviation

**Table 6: Test of significance for the mean internal gap on axial surfaces from three groups (Group 1, Group 2, and Group 3)**

| Descriptive statistics of internal fit on axial surfaces    | Sample number | Minimum | Maximum | Mean | SD | *F* | *P* |
|------------------------------------------------------------|---------------|---------|---------|------|----|-----|-----|
| Group 1                                                    | 10            | 81.49   | 94.73   | 87.60 | 3.71 | 976.44 | 0.001 |
| Group 2                                                    | 10            | 62.86   | 70.34   | 66.75 | 3.64 |     |     |
| Group 3                                                    | 10            | 28.65   | 35.48   | 32.97 | 2.00 |     |     |

SD=Standard deviation
Mean vertical marginal gap for metal ceramic crowns obtained from direct optical scanning of the metal die (G3) was 36.38 μm, showing comparatively lesser than the other two groups which could be attributed to the fact that this process has completely eliminated casting and manual errors, yields good results, compared to induction casting procedure which was used to melt the alloy.[8,34,36] Results of this study regarding the vertical marginal gap of all 30 copings were merely in acceptable range and in consensus with those of Dedmon.[10] White et al.,[30] Fusayama,[1] Hung et al.,[12] and Schwartz et al.[37]

The data obtained from this study showed that the mean internal gap for metal ceramic crowns obtained from inlay casting wax pattern was 87.6 μm (G1), metal ceramic crowns obtained from indirect optical scanning of the master die was 66.75 μm (G2), and metal ceramic crowns obtained from indirect optical scanning of the master die was 32.97 μm (G3).

The mean internal gap of G1 was 87.60 μm which was statistically more compared to G2, the discrepancies between mold expansion and casting shrinkage could be the reason for this. The mean internal gap of G2 was 66.75 μm which was statistically significant than G1. G3 showed a mean internal gap of 32.97 μm. Ucar et al.[39] did a study on internal fit evaluation of crowns fabricated using conventional casting technique and Laser sintered technology. Results from their study showed that the mean internal gap widths of cast Co-Cr copings were 87.6 μm and that of laser sintered technique was 32.97–66.75 μm which were in acceptance with the results obtained in this study.[17,10] Bindl et al.[39] reported internal gap width of 81 μm to 136 μm for different all-ceramic CAD/CAM crowns which were greater than the mean internal gap found in this study.

Conclusion

Vertical marginal and internal gap was measured for all thirty test samples using Steremicroscope in microns.

1. The order of discrepancy of vertical marginal gap is as follows:
   • Minimum vertical marginal gap for metal ceramic crowns obtained from direct optical scanning (G3) (31.9 μm) followed by from indirect optical scanning (G2) (70.4 μm) followed by conventional lost wax method (G1) (110.15 μm).

2. The order of discrepancy of internal gap is as follows:
   • Minimum internal gap for metal ceramic crowns obtained from direct optical scanning (G3) (28.65 μm) followed by indirect optical scanning (G2) (62.86 μm) followed by from conventional lost wax method (G1) (81.49 μm).

Within the limitations of this study, it has been concluded that the metal ceramic crowns fabricated by CAD/CAM method from direct optical scanning had the least vertical marginal and internal gap.

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Conflicts of interest

There are no conflicts of interest.

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