Original Article

In vitro evaluation of strain distribution on maxillary denture bases fabricated using compression molding, milling, and printing techniques

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Abstract

Purpose: *This in vitro study aimed to evaluate the strain distribution under static loading conditions on maxillary denture bases fabricated using computer-aided design and computer-aided manufactured CAD-CAM milling (CCM), 3-dimensional (3D)-printing (3DP), and conventional heat-polymerized resin compression molding (CM) methods.*

Materials and methods: *A maxillary edentulous reference model was scanned, and 2-mm-thick denture bases were designed and fabricated using 3 fabrication techniques: CCM, 3DP, and CM. A 45 N load was applied perpendicularly to each denture base, and the experiments were repeated 3 times for each denture base. A total of 7 strain gauges were attached to each denture base, including at the labial and buccal notches, the anterior palatal sites at the midline, the posterior palatal seal, and the ridge crest of tuberosity. Mean strain values (MSVs) recorded from the denture bases were compared. Statistical analyses were performed using the Mann–Whitney U test, Kruskal–Wallis test, and Wilcoxon signed-rank test. P< 0.05 was considered significant.*

Results: *Significantly higher MSVs were observed at the posterior palatal seal, ridge crest of tuberosity, and labial notches for all 3 types of fabricated dentures, especially for the CM technique. The lowest MSVs were recorded for the CCM group from the measurement sites, and the mechanical performance of the CCM and 3DP groups were similar under loading conditions. Additionally, divergent MSVs were observed for the 3DP measurement sites.*

Conclusion: *Within the limitations of the present study, CCM dentures exhibited lower MSVs under loading conditions than 3DP and CM dentures. CCM and 3DP dentures have similar mechanical performaces different from the pattern of CM dentures.*

Key words: **Compression molding, CAD-CAM milling, 3D printing, maxillary denture, strain distribution.**

Introduction

Although better support and retention can be achieved by using implant-retained overdentures[1], maxillary complete dentures continue to provide esthetic, phonetic, and chewing functions for edentulous patients who are not willing to undergo additional surgical processes[2]. Conventionally, polymethyl methacrylate (PMMA)-based dentures, fabricated using the compression molding (CM) technique, have been the most widely used denture type[3], due to good biocompatibility, easy processing, stability in the oral environment, acceptable aesthetics, and economic characteristics[4]. However, low-mechanical-strength resin bases are vulnerable to deformation during mastication and can crack or fracture when subjected to strong external stress[5]. A higher incidence of damage has been reported for maxillary dentures, according to clinical surveys [5,6]. Additionally, resin polymerization shrinkage can result in linear deformation of 0.4%–0.9% during processing. Denture deformation during processing affects prosthetic occlusion and dimensional accuracy, and denture distortion can increase the vertical dimension of an occlusion, which results in the increased necessity for laboratory and clinical adjustments[7,8].

Computer-aided design and computer-aided manufacturing (CAD-CAM) technology was first used to fabricate complete dentures in the 1990s,[9] and can currently be used in both subtractive (computerized numerical controlled milling) or additive (rapid prototyping) processes[10]. The CAD-CAM milling (CCM) technique produces dentures by machining a pre-polymerized PMMA block, which possesses the advantages of superior strength, fewer residual monomers, and less porosity than PMMA dentures formed using the CM technique[11-14]. The 3-dimensional (3D) printing (3DP) technique (rapid prototyping) has been rapidly developed during the past decade and has the advantages of less material waste and the ability to include intricate internal geometrical details[15]. However, light polymerization printed resin has lower surface hardness and higher flexural strength than conventional acrylic resin[16]. Information remains lacking in the mechanical properties of denture materials, including the strain distribution of denture bases fabricated using CM, CCM, and 3DP techniques under uniform testing conditions.

The purpose of this *in vitro* study was to compare the strain distribution of maxillary denture bases fabricated using CCM, 3DP, and CM techniques under a static load. The null hypothesis was that no differences in strain distribution would be observed among the different fabrication techniques.

Materials and methods

An edentulous maxillary cobalt-chromium alloy reference model fabricated in our previous study[17] was scanned (E3 3D scanner; 3Shape), and the scanning data were outputted as standard tessellation language (STL) files. Then, a PMMA maxillary edentulous test model (Hygienic resin, Coltene Whaledent) was duplicated from the reference model, with a 2-mm thickness artificial mucosa, using impression material (monopren, Kettenbach)[18].

Next, 2-mm-thickness denture bases were designed with a CAD software (3Shape Dental Designer; 3Shape) using the STL file from the reference model, and the denture bases were fabricated using CCM, 3DP, and CM techniques. Fifteen sets of denture bases were fabricated consisting five sets in each group (Fig. 1). In the CCM group, the denture bases were milled from Yamahachi PMMA blocks (Yamahachi Dental Mfg), using a 5-axis milling machine (CORiTEC

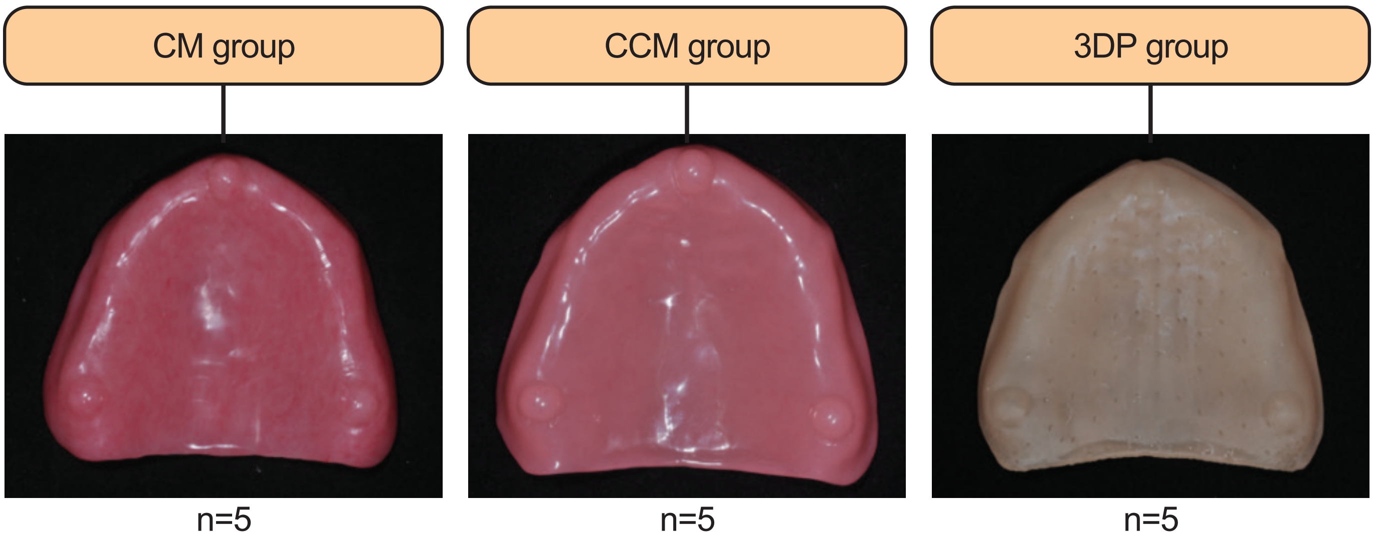

Figure 1. Denture bases fabricated using different techniques. CCM, CAD-CAM milling; 3DP, 3D printing; CM, compression molding.

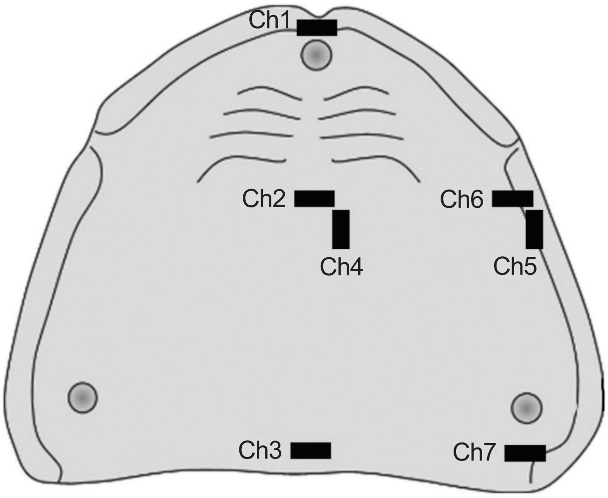

Figure 2. Positions of the strain gauges on the denture base, including Ch 1: labial notch; Ch 2: transvers anterior middle base plate; Ch 3: posterior palatal seal; Ch 4: axial anterior middle base plate; Ch 5: left buccal notch; Ch 6: left anterior ridge crest; and Ch 7: left ridge crest of tuberosity.

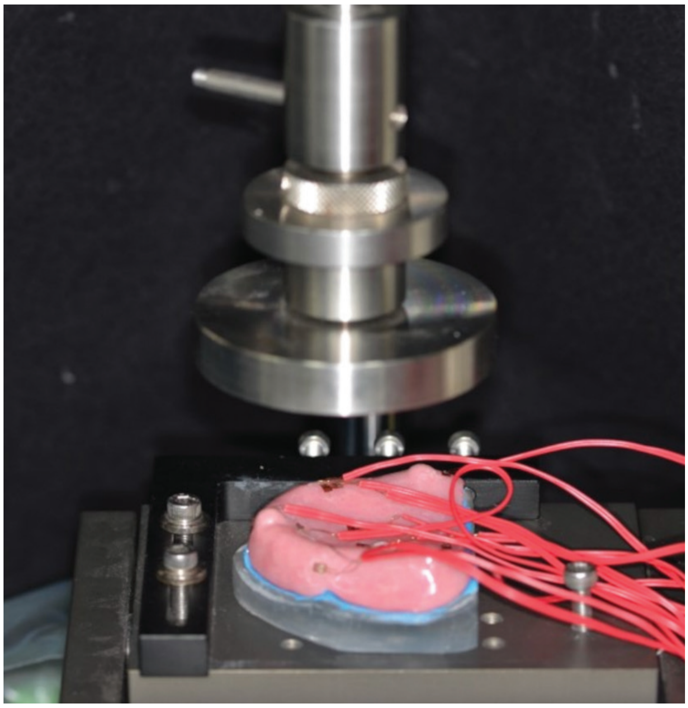

Figure 3. 45 N vertical loading on the denture base.

250i; imes-icore GmbH; Fig. 1). In the 3DP group, denture bases were printed from NextDent Base printable resin (NextDent BV), using a digital light processing (DLP) based printer (NextDent 5100 DLP printer, NextDent). In the CM group, according to pre-scanning data of reference model, the 2-mm thickness spacer for denture base was designed with a CAD doftware (Meshmixer, Autodesk Inc) and printed with printable resin (MiiCraft BV-005, Yong Optics Inc) by using the DLP printer (NextDent 5100). Then the spacer was placed on the reference model for packing procedure. The denture bases were fabricated using heat-polymerized PMMA resin (Luciton 199; Dentsply Sirona).

Seven miniature strain gauges (KFGS-2-120-C1, KFGS-2-120-D16, Kyowa Co) were attached to the polished surface of each denture base using specific cement (CC-33A, Kyowa) to measure the strain under loading, including at the labial notch (Ch 1); transvers anterior middle base plate (Ch 2); posterior palatal seal (Ch 3); axial anterior middle base plate (Ch 4); left buccal notch (Ch 5); left anterior ridge crest (Ch 6); and the ridge crest of left tuberosity (Ch 7) (Fig. 2). Each denture base was placed on the test maxillary model and mounted on a universal testing machine (TD-221; JobHo Technology). A 49-N axial load19 was applied perpendicularly to each denture base three times (Fig. 3). The outputs from the strain gauges were transferred to an analog/digital converter through an amplifier (PCD-300A, Kyowa Co). The mean strain values (MSVs) from strain gauge of each group were collected for comparison.

To determine differences between groups, the Kruskal–Wallis test, followed by Dunn's post hoc test (α =.05), was used to compare the MSVs between the CCM, 3DP, and CM groups. All data were analyzed using statistical software (IBM SPSS Statistics, v21.0; IBM Corp).

Results

Figure 4 shows the MSVs recorded at the various measurement sites for each denture base in the study; the positive and negative values represent tensile and compressive strains under loading, respectively. In general, the largest MSVs were recorded at the posterior palatal seal sites (Ch 3), followed by the anterior middle base plate (Ch 2) and the labial notch (Ch 1), along the middle line from posterior to anterior sites, in all 3 groups. The CCM group demonstrated the lowest tensile MSVs, whereas the CM group showed the largest compressive values at the posterior palatal seal. Additionally, larger MSVs were exhibited at the ridge crest of tuberosity (Ch 7), especially for the CM group. The mechanical performance in terms of tensile or compressive strain was similar between the CCM and 3DP groups but differed from that observed for the CM group. Moreover, the 3DP group showed larger variations in the results obtained from the measurement sites under loading in the study.

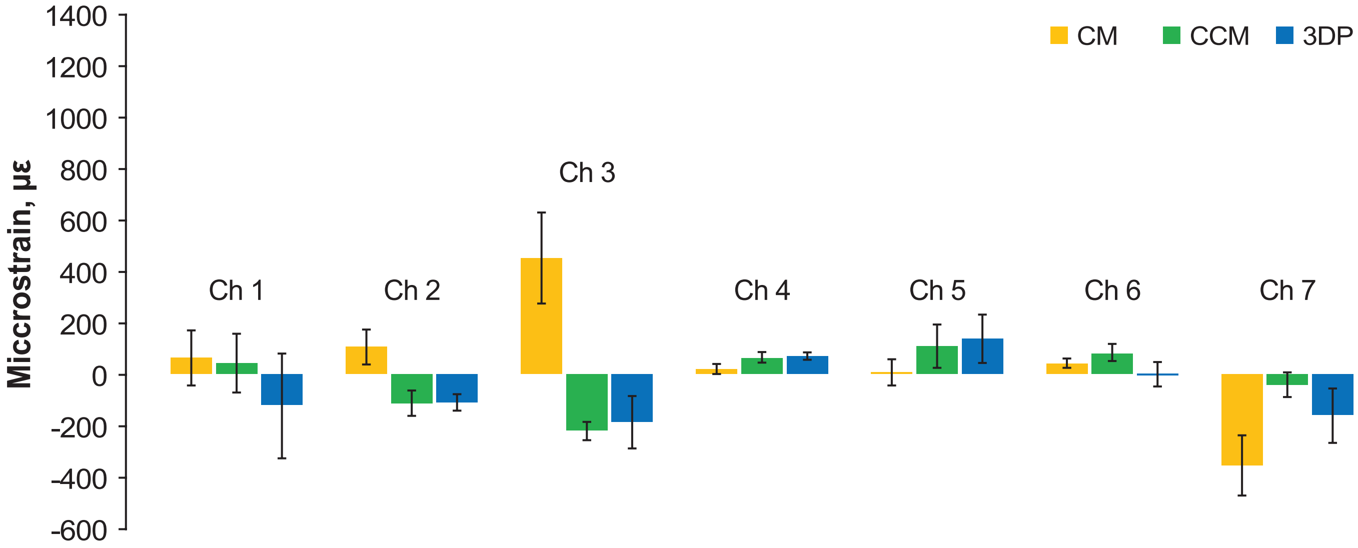

Figure 4. Strain distributions (με) in the CCM, 3DP, and CM groups. Data are expressed as the mean strain value (MSV) and standard deviation. CCM, CAD-CAM milling; 3DP, 3D printing; CM, compression molding.

Discussion

According to the results of the present study, the strain distribution on denture bases varies depending on the fabrication technique used. Therefore, the null hypothesis was rejected. Heat-polymerized PMMA resin CM techniques have long been used to generate denture bases due to acceptable aesthetics, ease of construction, and stable biocompatibility[2,3]. However, deformations during processing, lower mechanical strength, and poor fracture resistance can influence the treatment outcome[16,20]. According to a 3-year clinical survey, Tomita et al[5]. indicated that 70% of the patients experience denture fracture, especially at the midline of the maxillary denture. Several methods have been developed to improve the mechanical properties of dentures, such as the addition of a metal or fiberglass mesh framework to the denture base materials, which can improve the resistance to fractures [6,20]. With advances in CAD-CAM technology, prostheses fabricated by milling from pre-polymerization PMMA resin blocks have been reported to demonstrate increased fracture resistance and tensile strength[11-14]. Additionally, Hsu et al[17]. indicated that dentures fabricated using the CCM technique had higher adaption than those fabricated using other techniques, based on an *in vitro* evaluation.

In the present study, larger MSVs were measured at the posterior palatal seal, buccal notch, and ridge crest of tuberosity regions under loading conditions for denture bases fabricated using 3 different techniques. Significantly lower MSVs were recorded from CCM fabricated dentures, whereas the highest values were observed in those fabricated using the CM technique. Based on these findings, the pre-polymerized denture base material fabricated using the CCM process has higher mechanical strength than dentures fabricated using other techniques, similar to the findings reported by previous studies[11-14,17]. Similar mechanical performances in terms of tensile and compressive strain were observed for CCM and 3DP dentures, which differed from the pattern observed for CM dentures in the study. In addition, more divergent measurements were obtained in the 3DP group under loading conditions. Various factors can affect the outcomes of 3DP technology, such as the material properties of the printable resin, printing method, number of layers used, build angle, and postprocessing procedures[21]. Therefore, additional studies remain necessary to evaluate the impacts of these factors on the 3DP process.

To simplify the clinical conditions, 2-mm-thick, homogeneous denture bases were used in the present study, and a limited number of areas were measured using strain gauges, which allowed for the strain measurements at selected sites and the assessment of dimensional changes when loading forces were applied to the denture base. These may present limitations in the study. Additional studies remain necessary to evaluate the full stress/strain distribution across the complete denture area under clinical conditions, such as dentures containing teeth, containing supportive frameworks, or the use of different materials for CCM fabrication.

Conclusions

Within the limitations of this in vitro study, the following conclusions were drawn:

1. When a maxillary denture is placed under loading conditions, larger strain values were measured at the posterior palatal seal, labial notch, and ridge crest of tuberosity. The dentures fabricated using the CCM technique had the lowest MSVs under loading conditions compared with dentures fabricated using 3DP and CM processes.
2. Similar mechanical performances in terms of tensile and compressive strains were present for CCM and 3DP denrures under loading conditions, which differed from the pattern shown in CM dentures.

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