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Improvement of prosthetic device fit using a 3D scanner

***Lin Yang[1], Takayuki Kusunoki[1], Kazutoshi Kakimoto[2], Akiyo Kawamoto[1] and Kazuya Takahashi[1]**

[1]Department of Geriatric Dentistry, Osaka Dental University, 8-1 Kuzuhahanazono-cho, Hirakata-shi, Osaka 573-1121, Japan
[2]Department of Oral Health Engineering, Faculty of Health Sciences, Osaka Dental University, 1-4-4 Makinohonmachi, Hirakata-shi, Osaka 573-1144, Japan
**E-mail: 418211635@qq.com or kusunoki@cc.osaka-dent.ac.jp*

Purpose: We superimposed the digital scan data of a maxillary complete denture fabricated by microwave curing with the digital scan data of a physical working model, then investigated the change in fit by adjusting interference areas.
Methods: The scan data of 10 maxillary complete dentures fabricated by microwave curing and 10 working models were superimposed to investigate changes in fit according to adjustment of interference areas. The interference areas were then machined and re-evaluated.
Main results: The fit rates were 60.1±4.8% immediately after polymerization, 69.3±5.9% for the first round of grinding, and 73.4±6.0% for the second round of grinding. One-way analysis of variance showed that the compliance rate significantly increased with grinding. Additionally, multiple comparisons were made between uncut and first grinding, first and second grinding, and uncut and second grinding; the fit rate significantly increased in all cases. Repeated measurements and analysis of variance regarding deviation between the working model and the finished denture showed that the deviation was significantly reduced by grinding and the overall fit was improved; however, there were differences among the sites, and not all sites displayed similar improvement.
Principal conclusions: By superimposing the stereolithography data of a working model on the mucosal surface of a maxillary complete denture using a three-dimensional scanner, we were able to improve the fit. (J Osaka Dent Univ 2024; 58: 85-93)

Key words: Digital dentistry; Complete denture; Edentulous; Scanner

INTRODUCTION

Digital technology is continuously evolving and has become an integral aspect of dentistry. For example, although intraoral devices for obstructive sleep apnea fabricated with digital technology exhibit less accuracy than conventional methods, they have better retentive power.[1] Advances in digital technology have expanded the scope of applications for dental laboratory scanners each year,[2] and the number of units sold has been increasing in proportion to the growing demand. Digital technology has provided many advantages, such as the use of intraoral scanners to take impressions of patients who had difficulty with denture fabrication because of a stranger gag reflex. Digital technology has also enabled immediate denture fabrication using stored data, in the event of denture loss. In terms of accuracy, a study comparing fit rates between digitally fabricated and conventionally fabricated dentures showed that digitally fabricated dentures were sufficient for clinical application.[3]

In Japan, a hyper-aged society, complete denture fabrication is an important aspect of prosthetic treatment. It is difficult to obtain a prosthetic device with perfect fit, regardless of whether or not a precise impression is taken. Although various fabrication methods have been developed to improve denture fit, chairside adjustments are often required to improve fit when the denture is worn. Additionally, denture adjustments mainly depend on the dentist's experience, and minimal research has been conducted to determine the extent of grinding required to change denture fit. Identification and adjustment of interference areas in the laboratory can allow advance preparation of a prosthetic device with a good fit in the clinic, reducing treatment time.

In this study, we superimposed the scan data of a maxillary complete denture fabricated by microwave curing with the scan data of a working model, then investigated the change in fit by adjusting interference areas.

MATERIALS AND METHODS

Brazed denture fabrication

A plaster edentulous jaw model (G2-402, NISSIN, Kyoto, Japan) was used as the reference model (Fig. 1A). The residual crest morphology was classified as Type A according to the American College of Prosthodontists classification system, and the model had no undercut. A mold of the reference model was made with additive silicone impression material (Duplicorn, Shofu, Kyoto, Japan) for model replication, and 10 edentulous working models were replicated via carbide plaster (Modelock II, Shofu) (Fig. 1B). On one working model, an oc-

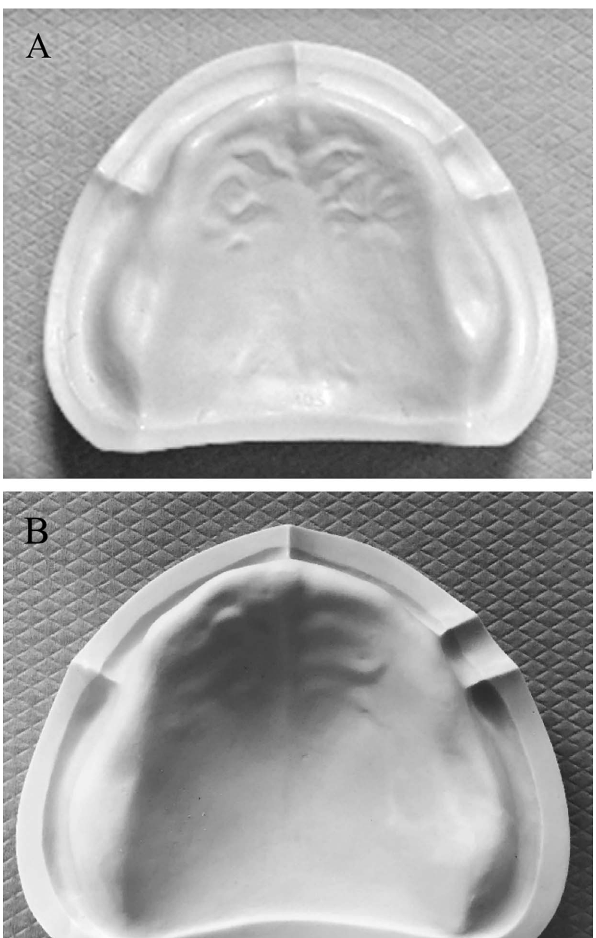


Fig. 1 Master model (A) and replica (B)

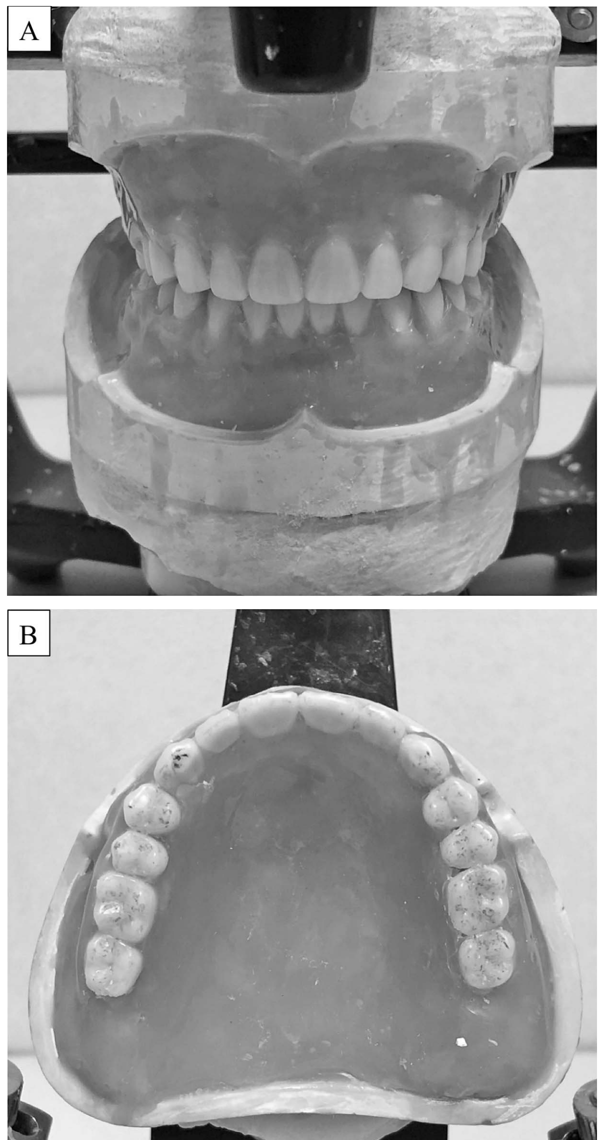


Fig. 2 Reference brazed denture with full balanced occlusion
A: Frontal view, B: Occlusal view

clusal base was fabricated with anterior and molar heights from the floor edge of 22 mm and 18 mm, respectively. The anterior, premolar, and molar widths of the occlusal crest were 5 mm, 7 mm, and 10 mm, respectively. Hard resin teeth (anterior: Veracea SA Anterior ST4, A3.5, molars: Veracea SA Posterior, S28, A3.5, Shofu) were placed with full balanced occlusion to fabricate the wax denture (Fig. 2A, B).

In a previous study, the authors investigated changes in fit by adjusting the interference areas of personal trays fabricated using a three-dimensional (3D) printer.[4] In that study, the team found that the maxillary fit was improved by grinding but the mandibular fit was not expected to improve by grinding; however, differences in fit were observed among sites.

To duplicate the wax denture, a mold of the base model was made with additive silicone impression material (Duplicorn, Shofu). To duplicate the wax denture, the artificial teeth were aligned in the mold, the duplicated edentulous jaw working model was covered, and melted wax was poured through a pouring hole. This process yielded 9 wax dentures that were nearly identical. In total, 10 wax dentures were fabricated along with the original dentures; these dentures were used in the study.

Polymerization method

The wax dentures were polymerized via dry heat polymerization (i.e., microwave polymerization). The fabricated wax dentures were embedded in flasks (FRP flasks, GC, Tokyo, Japan) using the American method. Dental plaster (AdvaStone, GC) was used for both primary and secondary implantation. After curing, the ring was opened and wax elimination was performed. Next, the microwave-cured denture base resin (Akron MC, GC) in the form of a rice cake was test-pressed at approximately 40 kgf/cm^2 and deburred three times. Polymerization was performed using a microwave oven (500 W; 2,450 MHz) for 3 minutes. Flasks that had undergone microwave irradiation were held at room temperature for at least 30 minutes to complete polymerization. They were then allowed to completely cool in cold water. Subsequently, the flasks were opened and the dentures were taken out with plaster forceps, then polished. In total, 10 maxillary complete dentures were fabricated.

Method of conformity investigation

The surface of the working model and the mucosal surface of the maxillary denture were scanned using a computer-aided design and manufacturing unit installed in a dental laboratory (S-WAVE Scanner D2000, Shofu), and the three-dimensional shapes were recorded. The resulting data were stored in stereolithography (STL) format and subjected to software analysis. The scanning data were processed with design software (Dental Manager Premium 2021, 3Shape, Copenhagen, Denmark). All 10 working models that had been replicated were scanned. The denture mucosal surfaces of the complete dentures fabricated on each working model were scanned in the same manner. The scanned data of the denture mucosal surface were inverted for superimposition with the working model data. The inverted area was defined as the area surrounded by the gingivobuccal transition zone. During denture mucosal surface scanning, a dye penetrant (Microcheck Developer, Ichinen Chemicals, Tokyo, Japan) was sprayed as thinly as possible. Analyses were performed using 3D measurement data evaluation software (GOM Inspect 2016, GOM, Brunswick, Germany) (hereafter GOM), which is a free software with functions such as 3D viewer, and 3-shape inspection; it can also identify differences between two sets of 3D data.

Data from the working model and the denture mucosal surface were superimposed by the analysis software, and the fitting accuracy was evaluated. Based on the analysis results, areas of possible interference were marked on the denture mucosal surface with a permanent marker, then adjusted by grinding with a cutting tool (Carbide Bar HP, Shofu). Next, the adjusted denture mucosal surface was scanned and superimposed on the working model data to evaluate the fitting accuracy. Based on the new analysis results, areas of possible interference were marked on the denture mu-

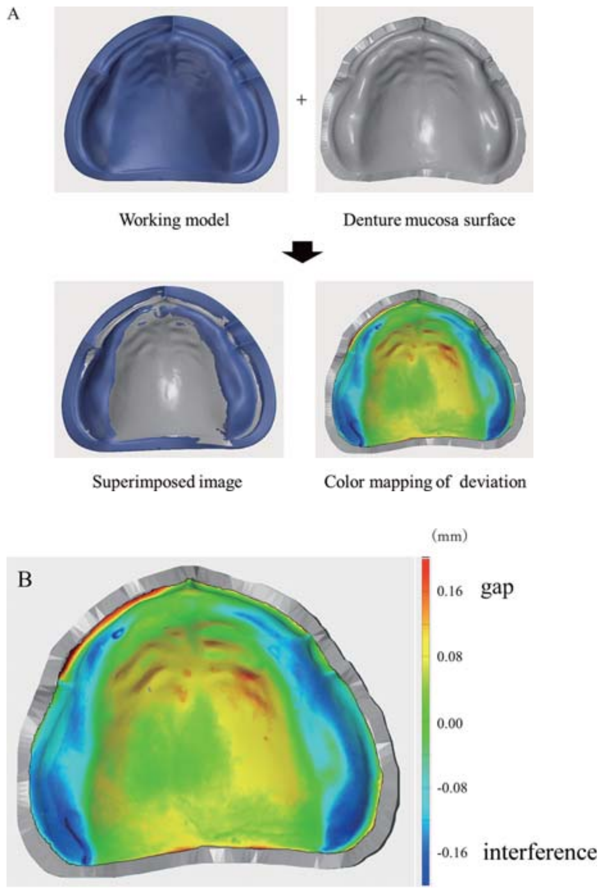
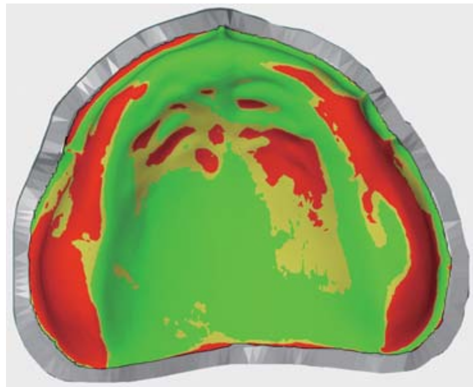


Fig. 3 Color mapping of overlap and deviation between working model and denture mucosal surface
A: Working model (upper left), denture mucosal surface (upper right), superimposed image (lower left), and color mapping of deviation (lower right)
B: Enlarged color mapping display
Red areas represent gaps, and Blue areas represent interference.



	Tolerance	Area	Percentage
	>100%	996.70	26.4%
	75%–100%	660.40	17.5%
	<75%	2125.29	56.2%

Fig. 4 Color mapping method displaying upper tolerance limit of ±0.10 mm and surface deviation of <75% defined as conformance ratio.
The green range was considered compliant. In this example, the fit rate was 56.2%.

cosal surface with a marker, then adjusted by grinding again. The grinding was performed with a focus on blue areas in the deviation color display (i.e., areas with negative deviation of ≥0.16mm). This process was repeated twice using cutting instruments to investigate how fitting accuracy varied with grinding. All interference area grinding was performed by the same researcher.

Analysis of scanning data

The scanned working model and STL data of the denture mucosal surface were initially superimposed by GOM, then superimposed using the best-fit algorithm method. Because the initial best-fit algorithm considers working model surface areas other than the denture mucosal surface, only the area corresponding to the denture mucosal surface was selected and superimposed using the "partial best-fit" method. The differences in superimposed data are visualized by color mapping in Fig. 3.

Fitness (tolerance)

Tolerance is defined as the difference between the maximum and minimum acceptable dimensional error relative to a reference value. In manufacturing and inspection processes, errors relative to the reference value must be considered. The role of tolerance is to establish an acceptable range of error based on the reference value, considering the variation in each process. In this study, ±0.10 mm was defined as the acceptable dimensional error and <75% surface deviation was defined as the fit rate relative to the surface area of the scan body. The fit rate is depicted in Fig. 4.

Deviation labels (working model vs. complete denture)

Deviation between the working model and the fin-

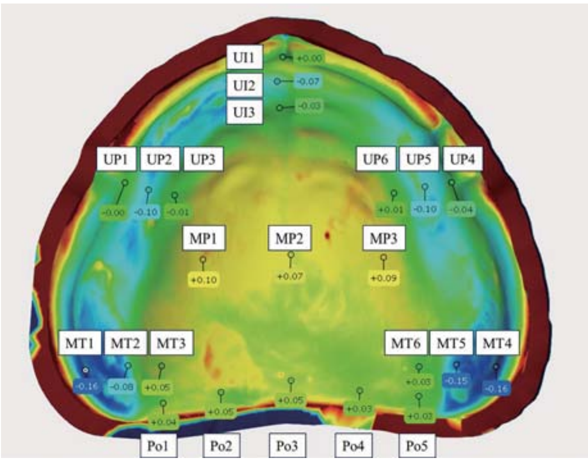


Fig. 5 Deviation measurement point and display of deviation at the measurement point: 3 points each on the left and right molars, 3 points each on the left and right premolars, 3 points on the anterior, and 3 points on the palate and 5 points on the posterior margin. There were 23 total measurement points.

ished denture was analyzed to identify the change in deviation immediately after polymerization, as well as changes after the first and second grinding sessions. 23 measurement points were labeled as deviation labels on the working model data. In the maxilla, 23 measurement points were established: 3 points each on the left and right lateral molars, 3 points each on the left and right lateral premolars, 3 points on the central incisor, 3 points on the palatal area, and 5 points on the posterior margin. Examples of the 23 measurement points and measurement results are shown in Fig. 5. The deviation labels are deviations between the working model and the complete denture; however, amounts of change were converted to absolute values to eliminate the effects of positive and negative error signs in the analysis.

Statistical processing

EZR statistical software was used.[5] Goodness of fit was determined using the Bonferroni multiple comparison test method after repeated measures analysis of variance; the number of variations was regarded as the main variable. The hazard ratio was set to 5%. For assessments of deviation labels, the Bonferroni multiple comparison test method was used after repeated measures analysis of variance; the numbers of grinding and sites were regarded as the main variables.

Table 1 Change in fit rate of each denture
S0: After polymerization, grinding 0 times
S1: Grinding 1 time
S2: Grinding 2 times

model No.	S0	S1	S2
1	56.2	71.0	74.9
2	58.7	63.5	69.3
3	68.7	81.6	85.2
4	66.6	72.2	79.5
5	62.8	68.4	71.2
6	62.0	74.5	77.7
7	52.6	68.6	72.0
8	56.0	58.7	64.6
9	56.8	65.4	65.4
10	60.7	68.7	74.6
Mean(SD)	60.1(4.8)	69.3(5.9)	73.4(6.0)

%(S.D.)

RESULTS

Scan body conformance rate

Fit rate (tolerance)

Table 1 shows the change in denture fit rate with grinding. The fit rate immediately after polymerization ranged from 52.6% to 68.7% (mean ± standard deviation: 60.1 ± 4.8%); the fit rate after the first grinding ranged from 58.7% to 81.6% (mean ± standard deviation: 69.3 ± 5.9%), and the fit rate after the second grinding ranged from 64.6% to 85.2% (mean ± standard deviation: 73.4 ± 6.0%). The minimum and maximum changes between immediately after polymerization and the first grinding were 2.7% and 16.0%, respectively; the minimum and maximum changes between the first and second grinding were 0.0% and 7.3%, respectively; and the minimum and maximum changes between the second grinding and immediately after polymerization were 8.4% and 19.4%, respectively. The increase in fit after grinding varied, but none of the sharpenings led to a decrease in fit.

The changes in 3D surface deviation color mapping due to grinding are shown in Fig. 6. Immediately after polymerization (Fig. 6A), the greatest negative deviation (light blue) was observed in the buccal area of the maxillary tuberosity; the buccal

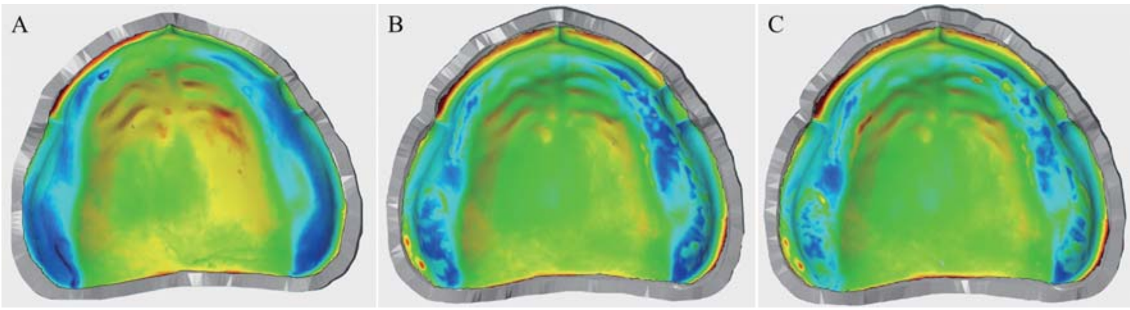


Fig. 6 Change in 3D surface deviation color mapping with grinding
A: After polymerization, grinding 0 times B: Grinding 1 time C: Grinding 2 times

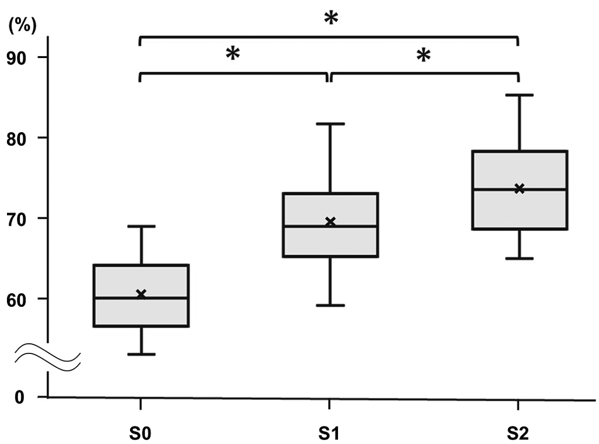
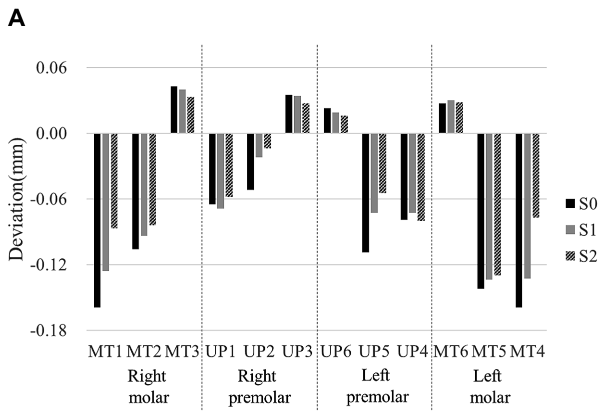


Fig. 7 Change in fit rate with grinding
S0: After polymerization, grinding 0 times
S1: Grinding 1 time
S2: Grinding 2 times
$n = 10$, *indicates $p < 0.01$



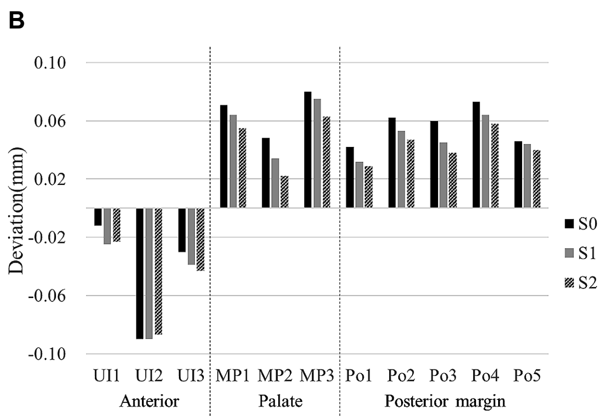


Fig. 8 Change-in deviation with grinding
S0: After polymerization, grinding 0 times; S1: Grinding 1 time; S2: Grinding 2 times
A: Premolars and molars
B: Anterior and palatal and posterior margin of palate;

area of the crests of premolars and molars also showed a negative deviation. These findings indicated that the mucous membrane surface of the denture was more medial (i.e., contracted) than the working model. In the context of the oral cavity, the light blue areas indicate areas of interference between the denture and the mucosa, which may have caused the nonconformity. In the palatal area, there was minimal deviation in the center (green), but positive deviation was observed in the alveolar area (yellow) and large positive deviations were observed in areas with palatal folds (red). Each grinding reduced the range of negative deviation in the buccal area of the maxillary tuberosity, while reducing positive deviation in the palatal area (Fig. 6B, C). The results of one-way analysis of variance with the number of grinding times as the main factor were statistically significant ($p < 0.01$). Thus, the fit rate significantly increased with grinding. Additionally, multiple comparisons were made between uncut (i.e., no grinding) and first grinding, first and

Table 2 Analysis of variance results for the effect of number of grindings and measurement points on the fit rate (deviation)

	SS	df	MS(SS/df)	P values	F values
Number of grinding	0.026	2	0.013	<0.01	51.97
Measurement Points	0.713	22	0.032	<0.01	19.37
Number of grinding* Measurement Points	0.047	44	0.001	<0.01	4.25

second grinding, and uncut and second grinding; the fit rate significantly increased in all cases ($p < 0.01$) (Fig. 7).

Deviation between working model and complete denture

Fig. 8 (A, B) shows graphical representations of the differences between working models No. 1 to 10. The deviation results are shown in Table 2. Repeated measures analysis of variance showed that both the number and site of grinding were statistically significant ($p < 0.01$), and the interaction was statistically significant ($p < 0.01$). The results showed that although the number of deviations was significantly reduced and the overall conformity was improved by grinding, site-specific differences were observed; improvement was not consistent among sites. Additionally, multiple comparisons were made between uncut and first grinding, first and second grinding, and uncut and second grinding; the deviation significantly decreased in all cases ($p < 0.01$). There were eight sites where the deviation decreased significantly, in the right and left buccal area of the maxillary tuberosity (MT1, MT4), central part of the palate (MP1, MP2, MP3), and posterior margin (Po2, Po3, Po4).

DISCUSSION

Superimposition of the working model and the finished denture revealed that the strongest interference was present in the maxillary tuberosity; interference was also present on the maxillary crest. The cause of interference was presumably that, when the denture was indexed, residual stress created during polymerization was released, leading to base resin deformation and manifestation of the interference. According to Uchida, microwave-cured denture base resin displays 0.52±0.22 mm of lift at the limb, 0.45±0.21 mm at the alveolar apex, and 0.47±0.21 mm at the central palatal area.[6] These extents of lift are likely caused by strong interference in the buccal area of the maxillary tuberosity, which results in denture lift, creating a larger gap in the central palatal area. In the present study, because the STL data were superimposed and the denture appeared to fit within the maxillary tuberosity, minimal palatal lifting was expected. Additionally, palatal deformation was considered almost negligible because the palatal area deviation decreased with grinding, although the palatal area was not subjected to grinding. Therefore, positive deviation of the palatal area immediately after polymerization was most likely caused by misalignment related to deformation of the floor margin.

Polymethyl methacrylate (PMMA) is a polymer obtained by polymerization of methacrylate ester. Its conformability is considered better than the conformability of heat-polymerized materials, with slightly greater lift at the edges and better conformability in the palatal area.[7] The material used in this study was the polymer PMMA, into which the monomer methyl methacrylate (MMA) was poured to form a rice cake. At the time of mixing, polymerization had not begun; however, when the resin was loaded into the flask and pressure was applied, the rice cake-shaped resin was packed without gaps. Subsequently, when the resin was heated in the flask, benzoyl peroxide generated radicals and the resin polymerization reaction began. However, even after polymerization, some MMA remained; this residual monomer can cause deformation.[8] The percentage of residual monomer in heat-polymerized resin is 0.2%-0.3%. The amount of residual monomer is related to the degree of polymerization (i.e., ratio of MMA to PMMA during polymerization). A higher degree of polymerization results in less residual monomer, whereas a lower degree of polymerization results in more residual monomer. Additionally, two contractions occur during the polymerization process. The first contraction is the polymerization shrinkage that occurs when MMA becomes PMMA ; the second contraction is the thermal shrinkage that occurs when the heated and thermally expanded resin reaches room temperature. These two contractions are collectively known as molding shrinkage. Various factors contribute to the molding shrinkage that influences denture fit. Teraoka stated that dentures were immersed in warm water at 37°C for 1 month after polymerization to release internal stresses and complete morphological changes (e.g., water absorption) before experimental analysis.[9] Additionally, PMMA significantly shrinks when stored in air; it does not completely shrink in water, even after 42 days of immersion.[10] In the present study, dentures were adjusted immediately after polymerization, and changes in fit were observed. However, further analyses are needed to determine whether the change in fit rate significantly differs when dentures are immersed in water for approximately 24 hours after polymerization, then grinded.

Recent studies have shown that analysis by 3D superimposition is effective for avoiding artificial measurement errors.[11] In the present study, the scan data were intended to be used to adjust the grinding of interfering areas for greater conformity. However, because a single dentist performed the grinding, it is important to examine whether differences in adjustment arise depending on the extent of the dentist's clinical experience. If there is a large difference, some modifications may be necessary to identify relevant grinding points and the extent of grinding for elimination of individual differences.

The mucosal thickness under the denture base considerably varies among sites. The mean thicknesses are approximately 2.3 mm in the molar region, 1.9 mm in the premolar region, 2.2 mm in the anterior region, 1.9 mm in the palatal crease wall, 1.6 mm in the central palate, and 1.8 mm at the palatal margin. The thickest area is approximately 5.6 mm on the lingual side of the molars, followed by 4.5 mm on the lingual side of the premolars.[12-14] The amount of pressure displacement, which refers to the degree of mucosal displacement or depression according to applied pressure, varies among regions. According to Miyashita, the mean amount of pressure displacement ranges from 0.7 to 1.0 mm.[12] Because an edentulous jaw exhibits considerable mucosal displacement, it is difficult to identify the denture limbus and establish appropriate pressure when taking impressions.

In the present study, sites with decreased deviation label values were right and left buccal area of the maxillary tuberosity (MT1, MT4), central part of the palate (MP1, MP2, MP3), and posterior margin (Po2, Po3, Po4). As mentioned in the section describing fit rate (tolerance), this result is presumably related to the various distortions that occur during denture fabrication. Because the denture mucosal surface deviation is approximately 0.2 mm relative to the amount of pressure displacement of the molar mucosa, the increase in pressure on the mucosa may cause lift, and patients often complain of pain when the denture is worn without adjustment. In this study, dynamic and compressive strains relative to mucosal tissues in the oral cavity were ignored. Additionally, various factors were not considered (e.g., denture storage in water, denture immersion in saliva, jaw crest morphology, denture base thickness, and scanning errors). Most studies consider a mucosal surface within an error range of 50 μm to exhibit conformance.[3, 13, 14] We believe that these points should be clarified in future studies.

In conclusion, by superimposing the STL data of a working model on the mucosal surface of a maxillary complete denture using a 3D scanner, we were able to visualize and quantify the fit; the fit was improved by adjusting the interference areas. This method of improving fit can easily be performed in dental laboratories. Therefore, it can allow dentists to obtain dentures that fit appropriately at the initial placement, which may help to reduce the examination time.

Conflicts of Interest
The authors declare no conflicts of interest associated with this manuscript.

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