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Three dimensional analysis on the deformation of the master cast during maxillary complete denture fabrication

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This study aimed to assess the changes in maxillary master casts that occur during complete denture fabrication, focusing on a compression molded denture. Digital merging techniques were used to measure the changes in 12 maxillary master casts at various fabrication stages. Measurements were performed from master cast formation to teeth arrangement using scanable ball markers and digital overlay techniques. The changes observed in the master cast were categorized as follows: S12 for the alterations from cast fabrication to occlusal rim formation, S23 for the alterations from recording jaw relations to teeth arrangement, and S13 for the overall changes throughout the entire fabrication process. The posterior seal area exhibited the most significant changes, until the jaw relation stage (S12). Statistical analyses revealed significant differences in changes among anatomical areas at different fabrication stages. These findings underscore the importance of considering alterations in the master cast during denture fabrication, when using traditional methods. Traditional techniques, such as the flask-pack-press, can induce substantial alterations in areas critical for denture retention and stability. This study highlights the need for a comprehensive assessment of fabrication processes to enhance denture quality and patient satisfaction. It provides valuable insights into master cast alterations that occur during complete denture fabrication. Efforts to minimize deformations in master casts are essential for improving patient satisfaction and oral health outcomes.

Keywords Edentulous, Complete denture, Denture retention, Denture stability, Laboratory

Abbreviations
CAD/CAM	Computer-aided design/computer-aided manufacturing
S12	From cast fabrication to wax rim formation
S23	From recording jaw relations to teeth arrangement
S13	From cast fabricaton to teeth arrangement
STL	STereoLithography
ANOVA	One-way analysis of variance
SPSS	Statistical package for social sciences

The primary goal of prosthodontic treatment is the restoration of function and improvement in esthetics to facilitate the recovery of oral health. Traditionally, the essential concepts in prosthodontics have been support, retention, and stability. Support refers to the resistance to vertical movement toward the denture base, whereas retention refers to the prevention of the influx of air between the tissues and the denture base under atmospheric pressure leading to movement away from the denture base. Finally, stability is the harmony between the final denture base and underlying tissues. Understanding the anatomical sites corresponding to these concepts enables a more comfortable and satisfactory denture experience for patients[1,2].

The clinical steps of complete denture fabrication are preliminary impressions, final impressions, jaw-relation record, esthetic and functional try-in, and denture delivery, typically involving an average of 5–6 visits. Successful clinical and laboratory procedures are essential for achieving successful outcomes[3,4].

Following the fabrication of a master cast, the subsequent fabrication stages involve the fabrication of a trial denture base with a wax rim according to the intraoral environment, recording jaw relations, and mounting the maxillary and mandibular master casts using a facebow transfer[5]. Subsequently, teeth arrangement is performed,

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and after the try-in, the final denture is processed. However, during the extensive laboratory processes, the master cast should undergo minimal deformation to ensure accurate results during actual denture processing[6].

Deformation of the master cast inevitably occurs during the fabrication process, possibly because of polymerization shrinkage of the acrylic resin during trial denture base fabrication[7,8], friction during wax rim fabrication, and repetitive contact between the maxillary and mandibular trial denture bases and master casts during teeth arrangement for achieving an ideal occlusal relationship. Additionally, various factors, such as deformation occurring during transportation between the dental laboratory and dental clinic and gypsum deformation over time, should be considered[9].

Although literature on the maintenance and preservation of master casts after impression-making is lacking, the manufacturer's instructions should be followed meticulously including an adequate setting time during master cast formation for satisfactory hardness and strength [10]. Additionally, application of a separating agent and blocking out of undercuts and buried areas for the fabrication of the trial denture base should be performed to prevent damage to the master cast. Furthermore, trimming of areas acting as undercuts between the trial denture base and master cast may be necessary for a passive fit, and the master cast should be protected from external impacts or material influx until the try-in is completed. However, research on master cast deformation is limited owing to constraints in analytical methods[11].

Abdulaziz AlHelal et al. (2017) introduced novel methods for denture fabrication, bypassing the traditional process of master cast fabrication and utilizing advancements in digital dentistry. Their findings indicated that Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) dentures, fabricated by intraoral scanning of denture base tissues, exhibited superior retention compared to conventional dentures[12]. Steinmassl et al. (2018) conducted a comparative analysis of conventional and digital denture fabrication techniques. Their study focused on the five significant anatomical indicators related to primary stability, secondary stability, retention, and border seal in prosthodontics and underscored the advantages of CAD/CAM approaches over conventional denture fabrication methods. Also, they emphasized the enhanced clinical adaptability and reduced frequency of oral ulcers associated with CAD/CAM dentures[13].

Many studies have primarily compared errors and differences in processing between conventional and digital fabrication methods, failing to interpret errors associated with the denture fabrication process, such as alterations in the master cast. Therefore, this study aimed to evaluate three dimensional change on the deformation of maxillary master cast alterations resulting from various fabrication processes as trial denture base & occlusal rim fabrication and teeth arrangement involved after maxillary master cast formation to the processing stage. The null hypothesis is that there is no difference in the master cast of maxillary complete dentures fabrication during the dental laboratory stages.

Methods
Study design
This study aimed to assess alterations in the master cast for the fabrication of maxillary complete dentures as a result of various laboratory processes involved before the final denture processing. The changes in the master cast occurring up to the stage before recording jaw relation (from cast fabrication to wax rim formation) were designated as S12, the changes in the master cast occurring up to the try-in stage (from recording jaw relations to teeth arrangement) were designated as S23, and the changes in the master cast occurring during the entire fabrication process were designated as S13 (Fig. 1). Digital merging was used to quantify these changes during conventional denture fabrication. Twelve casts were analyzed.

Fabrication process
The fabrication of the models involved final impressions with light-bodied polyvinyl siloxane impression material (Aquasil Ultra XLV; Dentsply Caulk, Milford)after border molding using one-step border molding technique with medium-bodied polyvinyl siloxane impression material (Aquasil Monophase Regular Set; Dentsply Caulk, Milford). After making the final impression, the impression was boxed, and a type IV dental stone (MG crystal rock, Maruishi, Japan) was mixed according to the manufacturer's instructions and poured in the impression to fabricate the maxillary master cast. The cast was set at room temperature for 24 h. Subsequently, scanable ball markers were placed at three points on the outer surface of the maxillary cast. One point was set on the outer

Fig. 1. Study design of three dimensional analysis on the deformation of the master cast. S12: period between master cast fabrication and jaw relation. S23: period between jaw relation and esthetic and functional try-in. S13: period between master cast fabrication and esthetic and functional try-in.
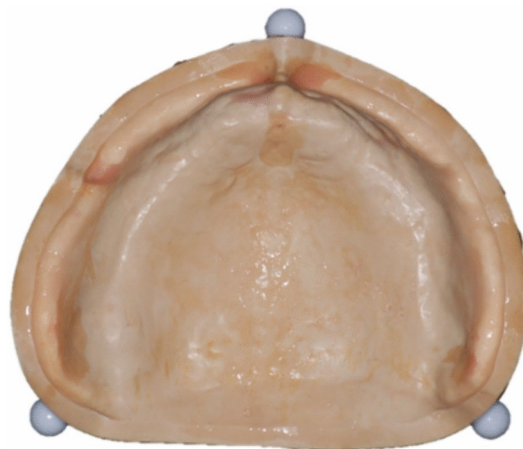
Fig. 2. Scanable ball markers were placed at three points (labial frenum and hamular notch) on the outer surface of the maxillary cast.
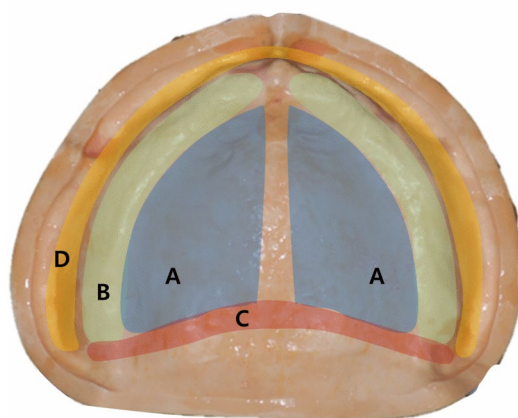
Fig. 3. Changes in the master cast were assessed according to anatomical regions. (**A**) Palate. (**B**) Alveolar ridge. (**C**) Posterior palatal seal. (**D**) Vestibule.

surface corresponding to the labial frenum, while two points were set along the extension line connecting the labial frenum and hamular notch, ensuring that the impression surface was included in the area formed by connecting the three points (Fig. 2).

During the fabrication process, for identifying the deformation and pattern changes on the master cast, the first scan were taken using desktop scanner. After blocking out the excessive undercuts, a thin layer of a separating agent (Acrosep, GC Corp., Tokyo, Japan) was applied on the impression surface of the master cast and allowed to dry. A trial denture base was fabricated on the master cast using the sprinkle-on technique with Ortho-Jet Powder (Lang Dental Mfg. Co., USA). The sharp edges of the trial denture base were trimmed, and the denture base was adjusted through multiple trial fittings. A wax rim was fabricated to establish the occlusal relationship, which included the process of the repetitive trial denture base insertion and removal. The second scan data were obtained after this step. After mounting the casts on the Hanau Modular semi-adjustable articulator, teeth arrangement (Endura, Shofu Inc., Kyoto, Japan) was performed to establish the occlusal relationship. The third scan data were acquired after the completion of teeth arrangement. The fabrication processes, including the fabrication of the maxillary master cast, trial denture base, and wax rims, teeth arrangement, and establishment of the occlusal relationship, were performed by a single dental technician.

Data processing
The InEos X5 scanner (Dentsply Sirona, USA) with a precision (0.0021 mm) was used for scanning, and data were processed in the STereoLithography (STL) format. Changes in the master cast were assessed at each stage according to anatomical regions, including the hard palate, alveolar ridge area, vestibule, posterior seal, and all regions (Fig. 3).

The extracted STL data were overlaid using Geomagic Control X software (3D Systems, USA). The overlay process involved segmenting the reference data (sensitivity 0.020 mm) to extract the ball markers and then
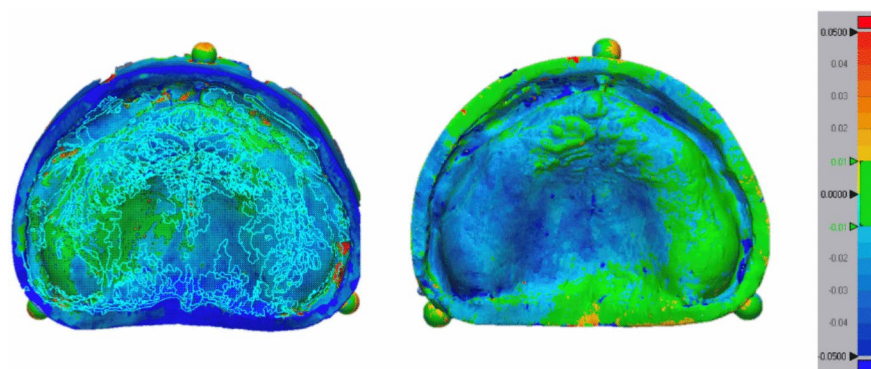
Fig. 4. Color maps representative of base fit to reference. Blue indicates negative deviations and red positive deviations (mm).

Outcome (S12)	Area	Mean ± standard deviation (mm)	p – value (Bonferroni)
	Palatal	− 0.014 ± 0.011	0.0025
	Alveolar	− 0.003 ± 0.009	> .9999
	Vestibule	− 0.008 ± 0.007	0.0062
	Posterior	− 0.033 ± 0.025	0.0021
	All	− 0.009 ± 0.009	0.0091

Table 1. Average changes in each anatomical area during the S12 stage.

overlaying the scan data at each stage around the three points to assess changes in the impression surface. Subsequently, the error in the shortest distance between datasets was measured. Color maps were also produced to demonstrate the qualitative three-dimensional differences between datasets (Fig. 4).

Statistical analysis

Since the data followed a normal distribution base on the result of the Shapiro–Wilk test, paired t-test was used to assess changes during each stage within each anatomical area and to compare the changes between S12 and S23 stage. To determine whether the changes in S12, S23, and S13 varied across the areas, a repeated measures ANOVA was conducted. The data was summarized as means with standard deviations. Adjusted p-values using Bonferroni correction were reported for multiple comparisons. Two-sided p-value < 0.05 was considered statistically significant. Statistical analyses were performed using SAS version 9.4 (SAS Institute, Cary, NC, USA).

Results

The results of the comparison of changes occurring in the master cast during the fabrication process of complete dentures are as follows:

The overall average change in the master cast was -9 μm (standard deviation [SD] 9 μm) for S12, -13 μm (SD 10 μm) for S23, and -23 μm (SD 11 μm) for S13, indicating a reduction in the volume of the master cast.

The differences among S12, representing changes up to the completion of wax rim formation after the fabrication of the master cast, S23, representing changes from the completion of wax rim formation to the completion of tooth arrangement, and S13, representing changes from the fabrication of the master cast to the completion of tooth arrangement, were statistically significant ($p < 0.0001$ for all).

For S12, the changes at various anatomical indicators were measured as follows: palatal −14 μm, alveolar ridge area −3 μm, vestibule −8 μm, posterior seal area −33 μm, and all areas −9 μm. Statistically significant changes ($p < 0.0001$) were observed in all areas except the alveolar ridge area (Table 1 and Fig. 5).

The largest change was observed in the posterior seal area, and compared with the other three areas, the difference was statistically significant ($p < 0.05$) when analyzed using Repeated Measures Analysis of Variance (RMANOVA) (Table 2).

For S23, the changes at various anatomical indicators were measured as follows: palatal −17 μm, alveolar ridge area −13 μm, vestibule −14 μm, posterior seal area −14 μm, and all areas −13 μm. All changes were statistically significant ($p < 0.0001$) (Table 3 and Fig. 6).

Although the palatal area showed the largest change (−17 μm) and the alveolar area showed the smallest change (− 13 μm), no statistically significant differences were observed among individual areas when compared individually (Table 4).

For S13, the changes at various anatomical indicators were measured as follows: palatal −31 μm, alveolar ridge area −16 μm, vestibule −22 μm, posterior seal area −47 μm, and all areas −23 μm. All changes were statistically significant ($p < 0.0001$) (Table 5 and Fig. 7).
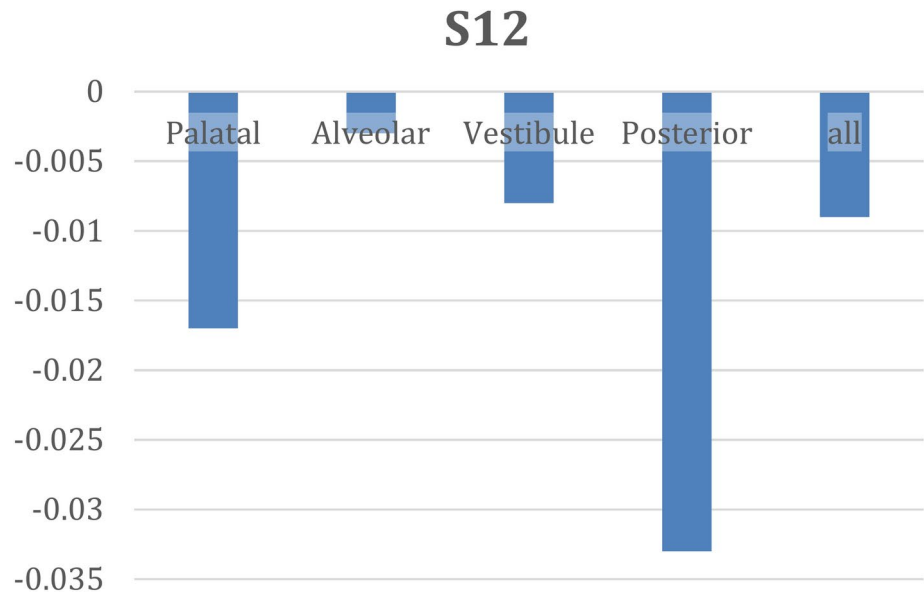
Fig. 5. Average changes in each anatomical area during the S12 stage (mm).

Post – hoc analysis	Difference Mean ± standard deviation (mm)	p – value (bonferroni)
Palatal vs. Alveolar	0.012 ± 0.006	0.0003
Palatal vs. Vestibule	0.006 ± 0.008	0.1222
Palatal vs. Posterior	− 0.019 ± 0.020	0.0497
Alveolar vs. Vestibule	− 0.006 ± 0.007	0.0985
Alveolar vs. Posterior	− 0.030 ± 0.017	0.0005
Vestibule vs. Posterior	− 0.025 ± 0.023	0.0171

Table 2. Average differences in changes in the master cast between anatomical areas during the S12 stage.

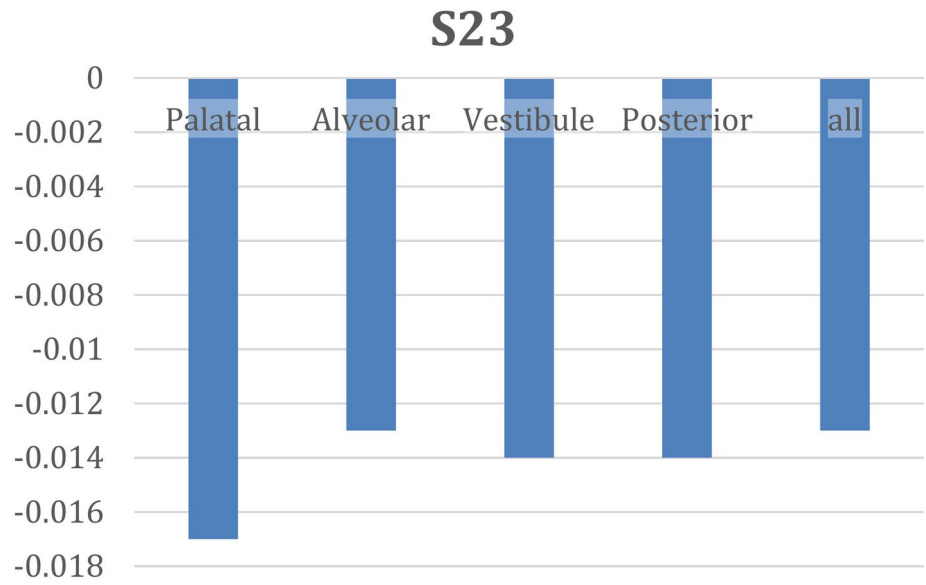| Outcome (S23)	Area	Mean ± standard deviation (mm)	p – value (Bonferroni)
	Palatal	− 0.017 ± 0.012	0.0019
	Alveolar	− 0.013 ± 0.011	0.0058
	Vestibule	− 0.014 ± 0.008	0.0003
	Posterior	− 0.014 ± 0.014	0.0163
	All	− 0.013 ± 0.010	0.0025

Table 3. Average changes in each anatomical area during the S23 stage.

The area with the largest change was the posterior seal area (−47 μm), followed by the palatal area (−31 μm). The area with the smallest change was the alveolar ridge area (−16 μm). While there was no statistical difference in changes between the posterior seal and palatal areas, statistically significant differences were observed in changes between other areas (Table 6).

The comparison of changes between the anatomical indicators at each fabrication step showed no statistically significant differences between S12 and S23 for all areas ($p > 0.05$) (Table 7).

Discussion

In this study, significant differences were observed in three dimensional change on the deformation of the master cast of maxillary complete dentures fabrication during the dental laboratory stages; therefore, the first null hypothesis was rejected. Brian et al. (2016) compared techniques used in denture processing using a ball marker and revealed variations ranging from 8 to 20 μm between methods employing CAD/CAM and Pack & Press. Therefore, in this experiment, the baseline was established by placing ball markers on the outer surface of the cast to quantify the mater cast deformation based on the overlapping patterns[14]. This allowed for the identification of indicators that remained unchanged despite changes occurring in the cast, enabling the observation of changes in the cast, which was not previously possible. Most experiments on denture master

Fig. 6. Average changes in each anatomical area during the S23 stage (mm).

Post – hoc analysis	Difference Mean ± standard deviation (mm)	p – value (bonferroni)
Palatal vs. Alveolar	0.004 ± 0.008	0.7914
Palatal vs. Vestibule	0.003 ± 0.011	> .9999
Palatal vs. Posterior	0.003 ± 0.020	> .9999
Alveolar vs. Vestibule	− 0.001 ± 0.007	> .9999
Alveolar vs. Posterior	− 0.000 ± 0.019	> .9999
Vestibule vs. Posterior	0.001 ± 0.019	> .9999

Table 4. Average differences in changes in the master cast between anatomical areas during the S23 stage.

Outcome (S13)	Area	Mean ± standard deviation (mm)	p – value (Bonferroni)
	Palatal	− 0.031 ± 0.014	< .0001
	Alveolar	− 0.016 ± 0.012	0.0028
	Vestibule	− 0.022 ± 0.006	< .0001
	Posterior	− 0.047 ± 0.020	< .0001
	All	− 0.023 ± 0.011	< .0001

Table 5. Average changes in each anatomical area during the S13 stage.

casts have not considered changes occurring during the fabrication process after the final impression stage of traditional clinical procedures. In this study, when CAD/CAM was used, no changes were expected in the master cast due to the scanning of the master cast. However, when fabricating dentures using the traditional method of flask-pack-press, which involves various processing steps, changes in the master cast were anticipated. Efforts were made to minimize errors by not using a scan spray during overlapping and by segmenting the areas to be overlapped. The experiment was conducted by overlapping the ball markers and comparing five anatomical areas.

Changes occurring in the cast during denture fabrication ranged from −16 to −47 µm in this study. Therefore, this study can be considered significant as it demonstrated changes in the master cast that occur with the traditional method of denture fabrication. The deformation in the master cast, in the posterior palatal seal area, were observed to be −47 µm. Accordingly, Brian et al. reported changes of -8 µm in the posterior palatal seal area with processing using the Pack & Press. However, according to the results of this study, changes of −47 µm can be expected in the master cast due to the fabrication process itself. Compared with fabricating dentures using CAD/CAM after master cast fabrication, larger changes can be anticipated with the conventional technique. Many previous studies have assessed differences and errors in the processing stage, but not changes in the master cast. By calculating the total errors in the complete denture fabrication process, which includes errors occurring
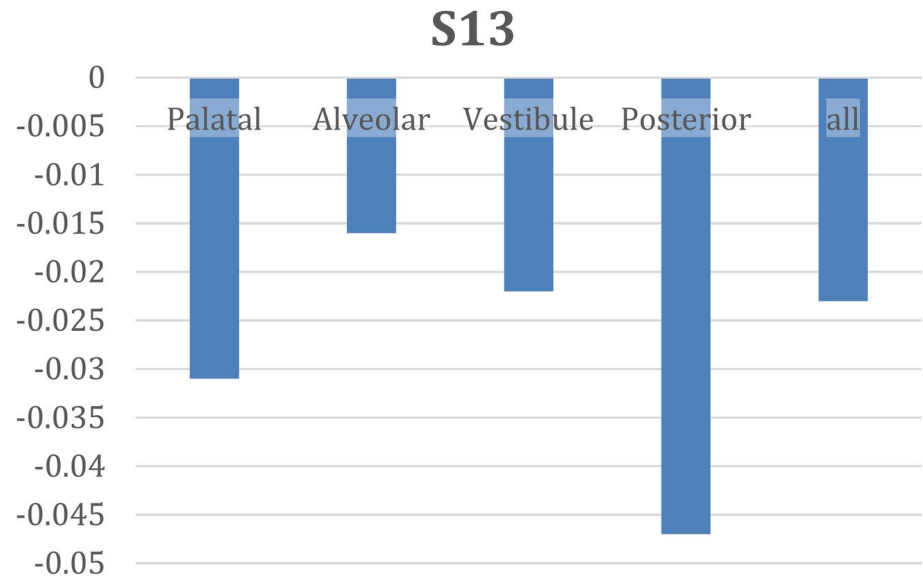
Fig. 7. Average changes in each anatomical area during the S13 stage (mm).

Post – hoc analysis	Difference Mean ± standard deviation (mm)	p – value (bonferroni)
Palatal vs. Alveolar	0.015 ± 0.007	< .0001
Palatal vs. Vestibule	0.009 ± 0.011	0.1389
Palatal vs. Posterior	− 0.016 ± 0.023	0.2104
Alveolar vs. Vestibule	− 0.006 ± 0.009	0.1976
Alveolar vs. Posterior	− 0.031 ± 0.020	0.0017
Vestibule vs. Posterior	− 0.024 ± 0.020	0.01

Table 6. Average differences in changes in the mast cast between anatomical areas during the S13 stage.

Area	S12 (mm) Mean ± SD	S23 (mm) Mean ± SD	Difference (mm) Mean ± SD	p – value
Palatal	− 0.014 ± 0.011	− 0.017 ± 0.012	0.003 ± 0.018	0.6368
Alveolar	− 0.003 ± 0.009	− 0.013 ± 0.011	0.011 ± 0.017	0.0535
Vestibule	− 0.008 ± 0.007	− 0.014 ± 0.008	0.006 ± 0.014	0.1785
Posterior	− 0.033 ± 0.025	− 0.014 ± 0.014	− 0.019 ± 0.035	0.0778
All	− 0.009 ± 0.009	− 0.013 ± 0.010	0.004 ± 0.015	0.4343

Table 7. Comparison of changes in the mast cast between S12 and S23. *SD* standard deviation.

during the denture processing stage and the deformations of the master cast along with errors from other laboratory processes, it is possible that these errors may exceed the critical threshold for mucosal adaptation of the complete denture. This can clinically impact the retention, support, and stability of the complete denture[15,16]. This study confirms that changes in the master cast owing to the fabrication process must be considered.

In this study, the overall average change in the master cast due to the fabrication process was −23 μm. Initially, when analyzing the statistical significance of changes in each area at different stages, significant changes were observed in all areas, except for the alveolar ridge area at S12, as the process progressed. This indicates that deformation of the master cast occurs predominantly in areas where the molding process undergoes more changes. Various factors such as polymerization shrinkage of the acrylic resin during trial denture base fabrication after mold formation, deformation due to friction during wax rim fabrication, repetitive contact between the maxillary and mandibular trial denture bases and master casts during teeth arrangement, deformation during transportation between the laboratory and the dental clinic, and gypsum deformation over time may contribute to these changes[17].

Moreover, while the overall change in the entire area at the final stage (S13) showed significant differences, the overall changes until jaw relation (S12) and the fabrication process just before try-in (S23) did not show

statistically significant differences. This suggests that it is difficult to attribute the excessive deformation at specific time points in S12 or S23 to the overall deformation. Therefore, dentists can consider the errors that occur during the fabrication process before communicating them to the patient. Additionally, with the digital method, considering the absence of changes in the master cast due to the initial scanning of the master cast, a better internal fit is expected[18]. However, in traditional fabrication processes, additional impressions may be obtained before processing to further enhance the integrity of the complete denture, owing to such deformations in the master cast[19]. If dentures are made after making additional impressions, the occurrence of complications, such as ulcers or denture stomatitis, which may occur during regular visits, will also decrease.

The time points were fixed stepwise (S12, S23, and S13), and the differences in changes in the master cast among each area were statistically examined. First, at S12, significant changes were observed in the posterior seal area compared to other areas. This can be attributed to deformationby anatomic undercuts and friction occurred in the posterior region during the repetitive process of placing and removing the trial denture base from the master cast. However, changes in the master cast at S23 were relatively uniform overall, and there were no statistically significant differences in changes among areas. This suggests that during the overall use and verification of the trial denture base after teeth arrangement, deformation occurred on the entire master cast rather than being concentrated in specific areas.

Currently, for most digital overlay techniques in the edentulous maxillary area, comparisons have been made only during denture processing. Therefore, this study is significant because it statistically analyzed the changes in the master cast, which were previously unrecognized, through ball markers and digital overlay techniques. However, the analysis was conducted using only the maxillary edentulous model, which is a limitation of this study. Further changes in edentulous patients can be predicted by assessing changes in the mandibular area in the future.

Conclusion
Within the limitations of this study, the following conclusions can be drawn:

1. The average change in the master cast during denture fabrication process was −23 μm, with noticeable increases in changes in the master cast as the fabrication steps progressed.
2. Changes in the maxillary cast during denture fabrication were evident, with a substantial difference of 33.0 μm in the posterior seal area up to the wax rim fabrication stage.

Data availability
The datasets used and/or analyzed in the current study are available from the corresponding author upon reasonable request.

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Author contributions

J.N. and J.O. planned experiment, carried out experiment, data analysis, took photographs, drafted the original manuscript. S.K. and S.P. helped coordinate the study and provided feedback on the results. J.N. conceived the concept and did critical revision on the manuscript. J.C. coordinated the study, planned experiment, supervised the project and critically reviewed the manuscript. All authors have read and agreed to the published version of the manuscript. All authors have provided consent for publication.

Declarations

Competing interests

The authors declare no competing interests.

Additional information

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