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ORIGINAL RESEARCH

Analysis of Modification Zones in Mandibular Complete Denture Models Designed with the Bio-Functional Prosthetic System

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Objective: This study aimed to analyze the regions and extent of modifications made to the final mandibular complete denture model designed using the bio-functional prosthetic system (BPS), compared to the initial model, utilizing digital scanning technology.

Methods: Twenty individuals with edentulism requiring mandibular restoration using BPS were included in the study. Digital scans of the initial and final gypsum models of the edentulous mandible were obtained. The models were aligned, registered, and analyzed for modification zones using Geomagic Warp software.

Results: Statistically significant differences were observed in three specific regions: the posterior fossa of the mylohyoid, the submandibular gland region, and the labial vestibule ($p < 0.05$). In contrast, differences in the posterior molar pad area were minimal ($p > 0.05$). Overall, the final model exhibited significant deviations from the initial model ($p < 0.05$), with the greatest variation observed in the posterior fossa of the mylohyoid and the least variation in the posterior molar pad area.

Conclusion: The final mandibular complete denture model, constructed using BPS, demonstrates improved accuracy in representing mucosal movement, shape, and positioning under occlusal pressure compared to the initial model. The posterior fossa of the mylohyoid, submandibular gland region, and labial vestibule exhibited enhanced delineation of mucosal movement boundaries, contributing to a more precise functional representation.

Keywords: bio-functional prosthetic system, complete denture, digital, edentulous jaws, impression

Introduction

The accurate representation and replication of the anatomical structures of the soft and hard tissues in edentulous jaws are fundamental for effective medical communication. The precision of the model plays a key role in determining if restorative objectives can be successfully achieved and constitutes one of the key factors influencing the success of restoration.[1]

In recent years, mandibular complete dentures using the bio-functional prosthetic system (BPS) have demonstrated superior retention, stability, and functionality compared to conventional dentures, making them a prominent focus of research.[2] During the restoration of edentulism with the BPS approach, two impressions are typically obtained. Initially, an anatomically accurate, non-pressure impression is used to fabricate an individualized tray, followed by a functional pressure impression taken with the personalized tray.[3]

The fundamental difference between these two impressions lies in the source of forces applied during the impression process. The initial impression relies on the application of pressure by the dentist to the tray, capturing a non-functional anatomical shape. Conversely, the final impression is influenced by the functional activity of the oral and jaw muscles of the patient, providing a more accurate representation of the dynamic state of the oral cavity during functions such as chewing and swallowing.[4]

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The mucosal static impression, also referred to as the non-pressure model, replicates oral tissues in a static state, closely conforming to the soft tissues of the oral cavity. This technique offers the advantage of excellent retention on the soft tissues and minimal deformation of the alveolar ridge. However, its primary limitation lies in its reduced stability under occlusal load.[5]

In contrast, the functional impression involves the application of controlled pressure to the supporting soft tissues of the denture, inducing functional reshaping to capture the deformed state of the tissues under load. This method excels in accurately recording the anatomical and functional conditions of oral soft tissues during denture function.[6]

In clinical practice, the adoption of functional pressure impressions has gained increasing recognition due to its capacity to replicate the dynamic biomechanical environment of the edentulous jaw. Specifically, practitioners report that this technique enhances the accuracy of mucosal displacement recordings during functional movements (eg, tongue protrusion and cheek contraction), which critically improves the predictability of denture adaptation under occlusal loads. Consequently, technicians can utilize these functional models to design denture borders with optimized extension and contour, thereby reducing chairside adjustments through improved spatial mapping of critical anatomical landmarks (eg, vibrating zone and retromolar pads).[2,7–9]

Despite these empirical advantages, however, in practical applications, the BPS imprinting technique also encounters some challenges and difficulties. Firstly, the acquisition of functional impressions requires patients to perform a series of functional actions (such as swallowing, speaking, etc) during the impression process, which demands a high level of patient cooperation. Secondly, the production of personalized trays requires precise non-pressure impressions as the basis, and obtaining high-quality non-pressure impressions also has certain technical difficulties. Moreover, the controllable pressure applied during the functional impression process needs to be precisely adjusted according to individual differences of patients, and either too much or too little pressure will not achieve the desired data results.

At present, there is no clear research conclusion regarding the differences existing between the two models. This study seeks to preliminarily examine the modification areas in the final model of complete BPS dentures when compared to the initial model. By using digital oral technology and based on BPS restoration cases, the objective of this study was to analyze the extent of modifications, discuss their clinical significance, and provide evidence-based insights to support the clinical application of complete BPS dentures.

Materials and Methods

A total of 20 individuals requiring BPS restoration, who visited the Strategic Support Forces Medical Center between January 2019 and December 2022, were included in this study. Approval for the study was obtained from the Medical Ethics Committee of the hospital (No. 20250507), and informed consent was obtained from all participants.

Inclusion and Exclusion Criteria

Inclusion Criteria

1. Patients with mandibular edentulism for a duration exceeding three months.
2. Patients presenting with edentulism and Class I mandibular alveolar ridge morphology, without evidence of soft or mobile alveolar ridges.
3. Patients without severe temporomandibular joint disorders.
4. Patients capable of understanding the purpose and significance of the study and willing to participate voluntarily.

Exclusion Criteria

1. Patients unwilling to undergo complete denture restoration.
2. Patients with mandibular alveolar bone conditions, such as bone spicules, bone protrusions, or soft alveolar ridges, that could interfere with experimental observations.
3. Patients whose language function, expression ability was limited or who have psychiatric disorders, and thus doctors cannot accurately obtain their discomfort complaints.

Model Preparation and Digital Transformation Standards

All model preparations were performed by senior attending physicians who had received standardized training, and complete dentures were fabricated strictly according to established operating protocols.[10]

Initially, Accudent XD edentulous trays and FCB non-pressure trays (Ivoclar, Liechtenstein) were used with Heraplast high-precision dental alginate (Zhongshan Deshanweiye Biotechnology Co., Ltd., China) to obtain preliminary impressions. The interocclusal distance and centric relation were recorded using Centric Tray centering trays (Ivoclar, Liechtenstein). On the preliminary plaster model, a personalized tray was fabricated with SR Ivoclean self-curing resin (Ivoclar, Liechtenstein), border molding was performed, and a Gothic arch was placed. A closed-mouth functional impression was then taken with virtual silicone rubber impression material (Ivoclar, Liechtenstein) in combination with the Accu-Dent Edentulous Tray, and a working model was cast in hard gypsum. After adjusting the Gothic arch, the vertical dimension was determined and the horizontal relationship was recorded using the Gothic arch tracing method. The upper and lower working models were subsequently mounted on a fully adjustable articulator using a facebow transfer. Finally, digital scans of the initial and definitive models were obtained with a 3Shape intraoral scanner (3Shape, USA) by Beijing Lelejia Medical Technology Co., Ltd. Subsequent steps, including wax pattern fabrication, clinical try-in, denture fabrication, and the return of digital scan data, were completed in accordance with standard protocols.

Matching and Data Analysis

The digital models were annotated by two experienced clinicians into seven functional regions: A. Buccal shelf area; B. Mandibular mylohyoid ridge; C. Posterior molar pad; D. Posterior fossa of the mylohyoid; E. Sublingual gland; F. Labial vestibule; G. Lingual vestibule (Figure 1).

For each patient, the initial and final digital models were aligned, registered, and compared using Geomagic Warp 2021 software (Geomagic, USA). The "best-fit registration method" was applied for model alignment, and both overall deviations and deviations within each annotated region were calculated (Figure 2).[11]

Statistical Analysis

Statistical analyses were conducted using SPSS 22.0 software. A one-way analysis of variance (ANOVA) was conducted to compare the overall deviations and modification amounts between the two model groups across the designated areas. Measurement data were presented as mean ± standard deviation ($\bar{x} \pm s$), and statistical significance was defined as $p < 0.05$.

Results

In this study, there were 8 male participants and 12 female participants. The average age was 76.95 ± 6.13 years, and the duration of denturelessness was 6.10 ± 3.78 months. See Table 1.

The three-dimensional deviation fitting maps, generated after the registration of the initial and final models, are presented in Figure 3. The analysis revealed a statistically significant overall modification difference between the initial and final models, measured at 0.98 ± 0.14 µm ($p < 0.05$). Significant differences in modification amounts were observed in the posterior fossa of the mylohyoid, sublingual gland, and labial vestibule, with mean deviations of 0.5 ± 0.23 µm, 0.33 ± 0.14 µm, and 0.51 ± 0.12 µm, respectively, as depicted in Table 2 ($p < 0.05$).

In contrast, the posterior molar pad area exhibited no statistically significant difference in modification amount (0.09 ± 0.07 µm, $p > 0.05$), as depicted in Figure 4. Overall, significant differences were observed between the initial and final models, with the posterior fossa of the mylohyoid revealing the largest deviation and the posterior molar pad area indicating the smallest deviation (Figure 5).

Discussion

In edentulous patients, the rate of mandibular bone resorption is faster than that of the maxilla, leading to more complex clinical manifestations.[12,13] This study investigates edentulous mandibles through clinical cases involving bone-supported prostheses (BPS). The digital scans of the initial and final models of edentulous mandibles were analyzed

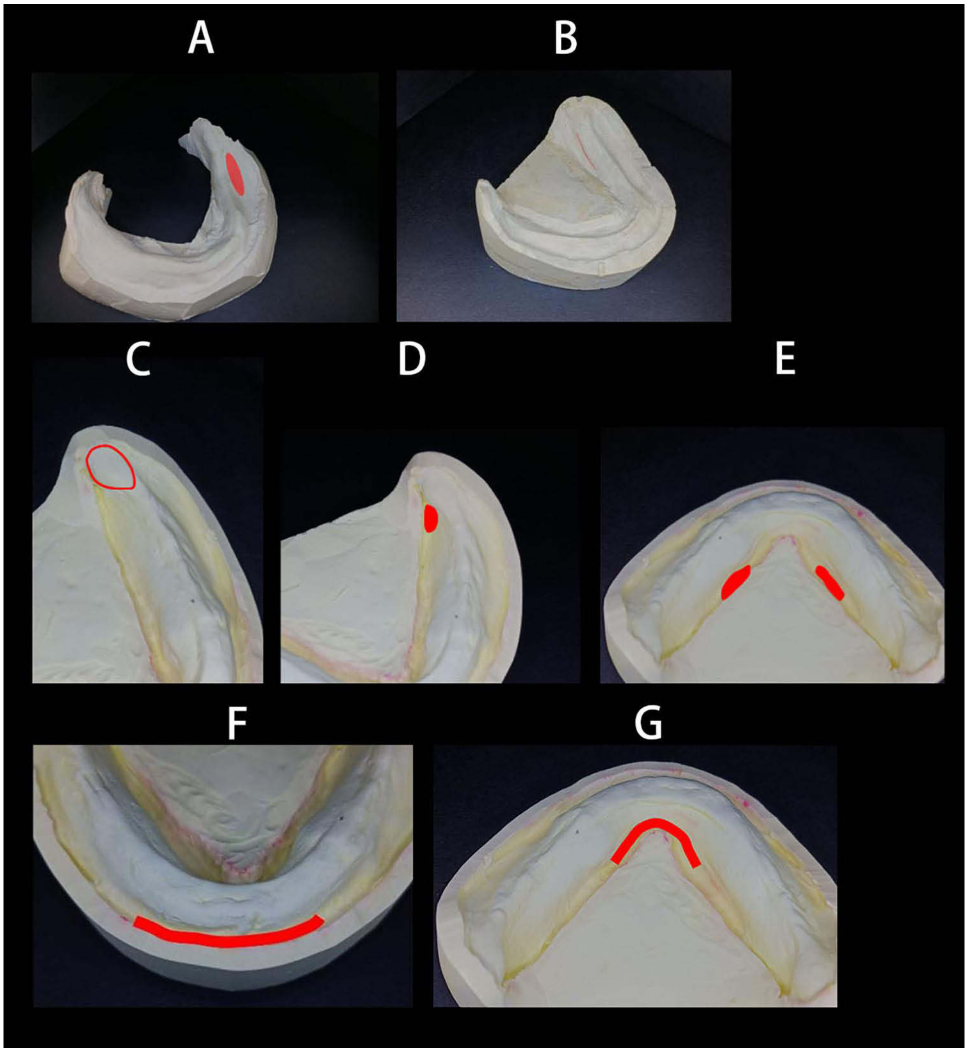

Figure 1 Identification of seven functional zones in the edentulous mandibular jaw. (**A**) Buccal shelf area; (**B**) Mandibular mylohyoid ridge; (**C**) Posterior molar pad; (**D**) Posterior fossa of the mylohyoid; (**E**) Sublingual gland region; (**F**) Labial vestibule; (**G**) Lingual vestibule.

and compared to identify the areas of modification. The analysis revealed that the primary areas of modification in the initial models included the posterior concavity of the genioglossus muscle, the sublingual gland area, and the labial-buccal sulcus, while minimal differences were observed in the posterior molar pad and alveolar ridge crest regions.

The final model more accurately represents the shape and relative position of the oral mucosa in edentulous patients under pressure. Moreover, it more effectively reflects the states of the posterior concavity of the genioglossus muscle, the sublingual gland area, and the labial-buccal sulcus. These findings indicate that the final model can better present the morphology of oral tissues in a functional state, thereby facilitating improved marginal seal under functional conditions. The posterior cranial fossa of the genioglossus muscle refers to the space located at the center of the genioglossus muscle.[14] Anatomically, it is defined by the genioglossus muscle anteriorly, above the posterior molar pad, and by the palatoglossus muscle posteriorly, laterally, and medially. Extending the denture border into this area can enhance retention without causing discomfort. Some studies have proposed that during the border molding process, lingual muscle activity pushes the border of this area into the posterior cranial fossa of the genioglossus muscle, forming an S-shaped curve on the surface of the model. The posterior border of the lingual flange of the denture is usually determined by connecting a landmark line 4–6 millimeters below the genioglossus crest with the posterior molar pad.

In cases of severe alveolar bone resorption, the denture border may extend posteriorly and inferiorly into this area, thereby enhancing the retention and stability of the denture.[15] However, excessive extension may cause pressure

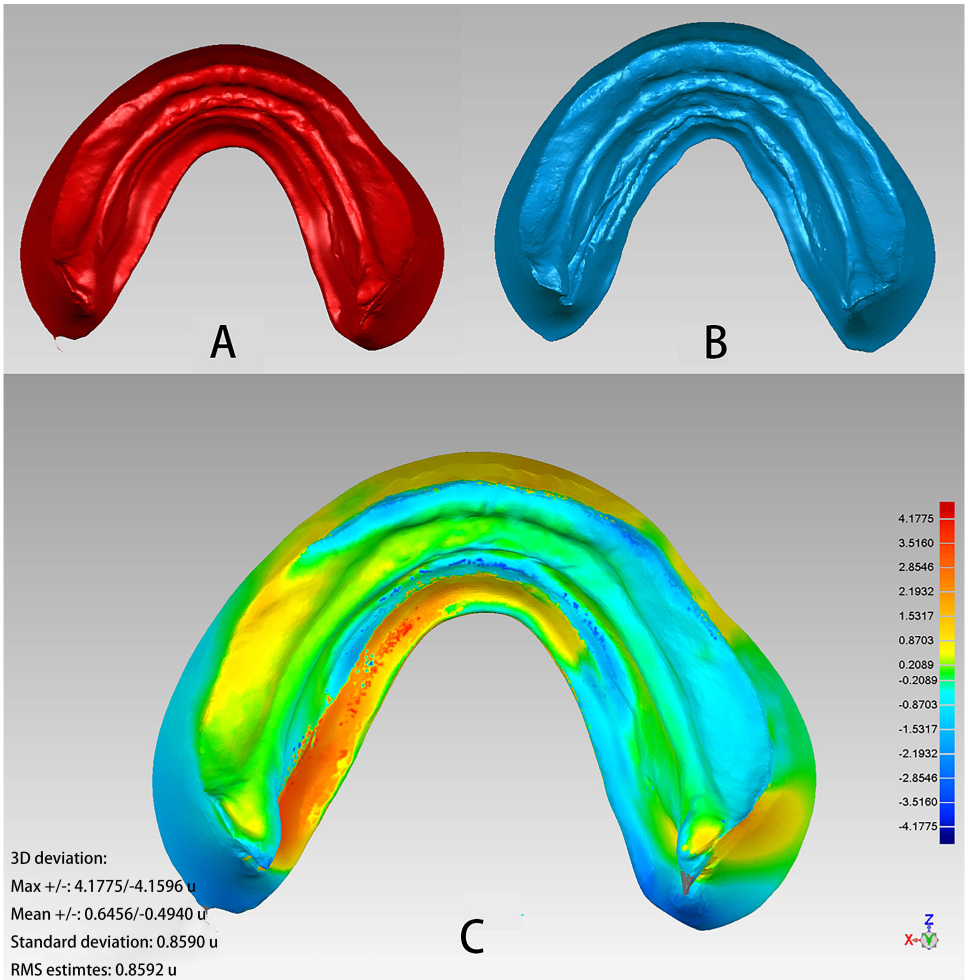

Figure 2 Best-fit analysis of the edentulous mandibular model using Geomagic warp. (**A**) Scan of the initial model; (**B**) Scan of the final model; (**C**) Three-dimensional color deviation map.

discomfort in the base of the tongue. Therefore, accurately capturing the functional position of this area through functional impression is crucial for successful complete denture restoration. During the functional impression process, a personalized tray and specific operating methods are used, such as applying lingual pressure to the tray during mouth closure and performing swallowing actions, to ensure that the posterior concavity of the genioglossus muscle is accurately presented.[16] Experimental data comparison shows that there is a difference of 0.87–1.27 millimeters between the initial impression method and the functional impression method in the posterior concavity of the genioglossus muscle. The final model can accurately reflect the functional state of the posterior genioglossus muscle under stable denture retention. This improved presentation ensures more accurate closure of the lingual flange during mastication, reducing retention problems caused by insufficient length or food impaction, as well as discomfort caused by excessive length and pressure on the base of the tongue.

During swallowing, the submandibular gland is elevated due to the contraction of the genioglossus muscle. When obtaining an anatomic impression, excessive movement of the patient's tongue tip may cause the model to fail to accurately reflect the position of the oral floor mucosa in an overly elevated state. Dentures made from such models may have insufficient extension in the lingual flange area. When the masseter muscle is relaxed, a gap may appear between the oral floor mucosa and the denture, thereby disrupting the marginal seal of the denture. To solve this problem, during the impression-taking process, using a personalized tray and performing functional molding in a closed-mouth state can relax the masseter muscle. This ensures that the oral floor fully reflects the depth of the lingual sulcus, thereby achieving better marginal seal of the lingual flange of the denture.[17] In this study, the comparison between the initial and final models

Table 1 Basic Data of Participants

Patient ID	Sex	Age (Years)	General Condition	Duration of Edentulism (Months)	Has Informed Consent been Signed
1	Female	85	Hypertension, coronary artery disease	10	Yes
2	Male	64	Hypertension	5	Yes
3	Male	74	Hypertension, post-cardiac stent procedure	7	Yes
4	Male	78	Diabetes	5	Yes
5	Female	70	Healthy	4	Yes
6	Male	67	Systemic lupus erythematosus	4	Yes
7	Female	86	Diabetes	6	Yes
8	Female	84	Diabetes, hypertension, coronary artery disease, peripheral neuritis	3	Yes
9	Female	82	Healthy	3	Yes
10	Female	71	Hypertension, hyperlipidemia	7	Yes
11	Female	76	Healthy	6	Yes
12	Male	75	Hypertension	5	Yes
13	Female	78	Coronary artery disease	5	Yes
14	Female	76	Hypertension, hyperglycemia	5	Yes
15	Female	81	Hypertension	9	Yes
16	Male	79	Hypertension	4	Yes
17	Male	81	Post-myocardial infarction intervention	20	Yes
18	Female	74	Hypertension	4	Yes
19	Female	73	Type 2 diabetes	7	Yes
20	Male	85	Healthy	3	Yes
Mean		76.95		6.1	

showed a difference of 1.00 to 1.45 millimeters in the submandibular gland area. The final model can more accurately reflect the state of the submandibular gland during stable denture retention. Even when the submandibular gland is lifted during swallowing, the lower denture can still remain stable because the upper and lower dentures have established a stable occlusal contact on a stable framework. In addition, the soft and elastic nature of the submandibular gland, combined with the presence of sufficient saliva, enhances the sealing effect of the lingual flange of the denture.

During the impression-taking process of the labial-buccal sulcus, the main influencing factors are the orbicularis oris muscle and the mentalis muscle. The orbicularis oris muscle runs horizontally within the labial-buccal sulcus. In elderly patients with weakened muscle strength, excessive stretching of the lower lip during initial impression-taking often leads to excessive extension of the sulcus line. This excessive extension can cause pain in the area and instability of the denture when pronouncing sounds like “oo”. The attachment point of the mentalis muscle is higher than the bottom of the labial-buccal sulcus. During the border molding process in this area, excessive stretching of the lower lip can trigger conscious contraction of the mentalis muscle, thereby shallowing the labial-buccal sulcus and thinning or shortening the impression border. This can lead to inadequate closure of the denture border. In this study, we observed a difference of 1.38–1.54 millimeters between the initial and final impressions of the labial-buccal sulcus, which was the largest deviation recorded in this experiment. The labial-buccal sulcus is also identified as one of the most challenging areas for impression-taking in elderly edentulous patients. These patients usually have a shortened lower third of the face, prognathism of the mandible, and protrusion of the lower lip, which remains in this state even without dentures. The decreased strength of the orbicularis oris muscle and increased activity of the mentalis muscle further complicate the denture restoration in this population. The final impression is taken in a closed-mouth state, using a personalized tray with a Gothic arch, which temporarily restores the height of the lower third of the face. This method, combined with actions such as pronouncing sounds like “mm” and “uh”, can more accurately reproduce the functional movement of the labial and buccal mucosa.[18]

The main goal of mandibular denture restoration is to restore occlusal function. However, achieving this goal is challenging due to various influencing factors, among which impression-taking techniques play a key role in the

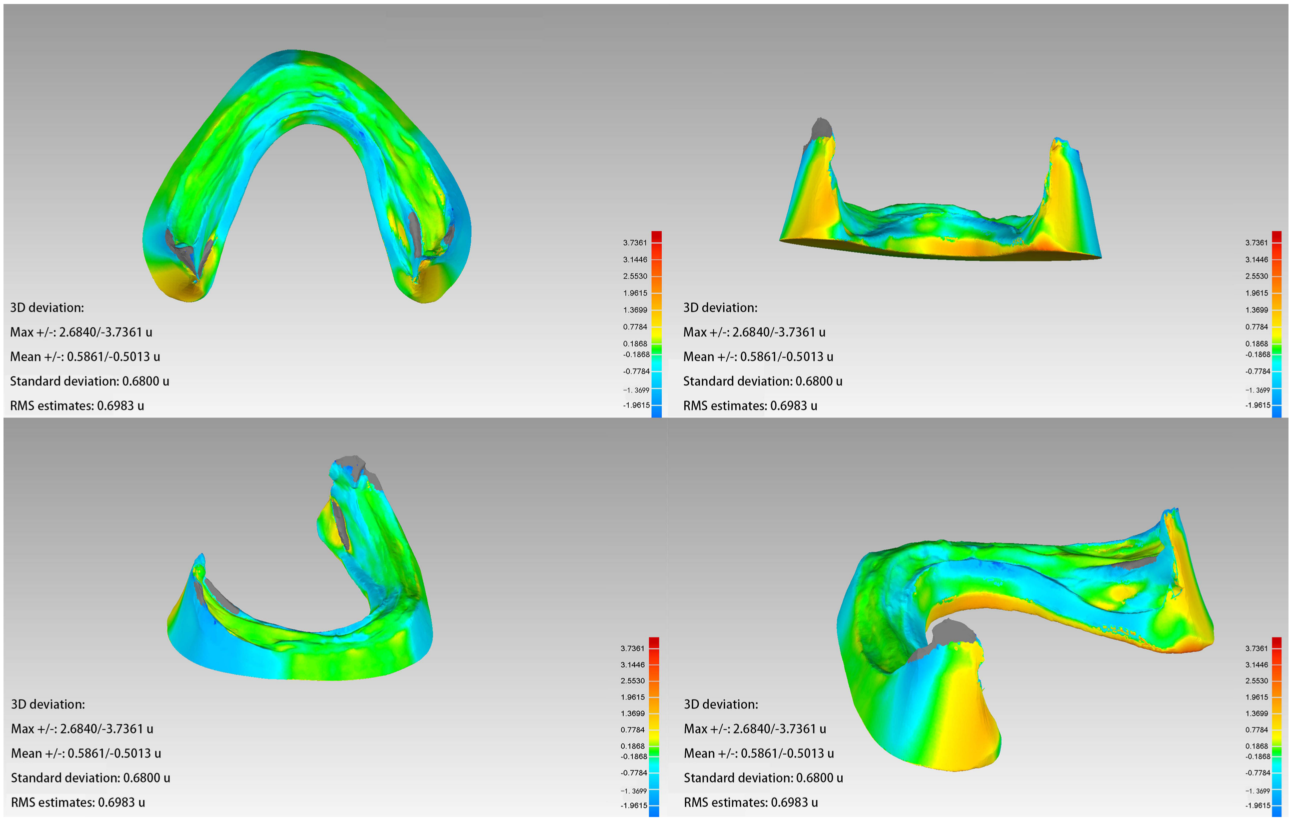

Figure 3 Color deviation maps depicting the differences between the initial and final models of the edentulous mandible in each functional area after best-fit matching.

fabrication of mandibular dentures.[19,20] In the past few decades, functional impression-taking techniques have made significant progress. For example, in-depth understanding of key aspects such as the buccal-lingual closure point has greatly promoted the development of complete dentures. Along with the theoretical progress of complete dentures, emerging technologies from other disciplines have also made further contributions to their development. Digital dentistry has been successfully applied in fixed restorations.[21] In addition, numerous studies have used three-dimensional finite element modeling to analyze various mechanisms, which has been widely used in fields such as maxillofacial surgery, prosthodontics, and implantology. However, the application of three-dimensional finite element modeling in the field of

Table 2 Modification Amounts of the BPS Final Model of Mandibular Complete Denture Compared to the Initial Model After Best-Fit Matching (n = 20, $\bar{x} \pm s$, μm)

Group	Initial-final Impression Difference	*p*-value
Overall model	0.98±0.14	0.035
Buccal shelf area	0.46±0.15	0.045
Mandibular mylohyoid ridge	0.39±0.19	0.047
Posterior molar pad	0.09±0.07	0.064*
Posterior fossa of mylohyoid	0.5±0.23	0.042
Sublingual gland	0.33±0.14	0.037
Labial vestibule	0.51±0.12	0.006
Lingual vestibule	0.53±0.05	0.011

Note: For the buccal shelf area, mandibular mylohyoid ridge, posterior molar pad, posterior fossa of the mylohyoid, and sublingual gland region, modification amounts were measured independently for the left and right sides following fitting and registration. The final modification amount for each area was calculated as the average of the measurements from both sides. *p > 0.05.

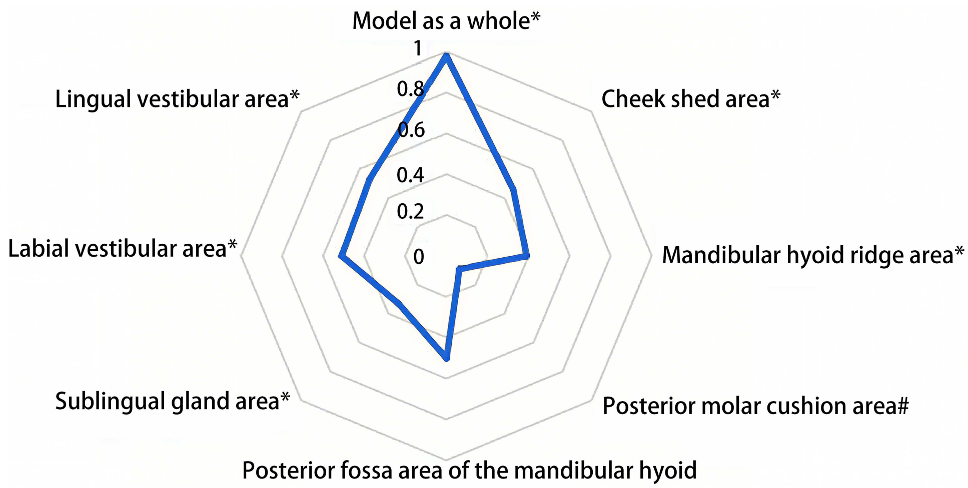

Figure 4 Mean modification values of the initial and final models of the edentulous mandible across functional areas following best-fit matching (*: p < 0.05, #: p > 0.05).

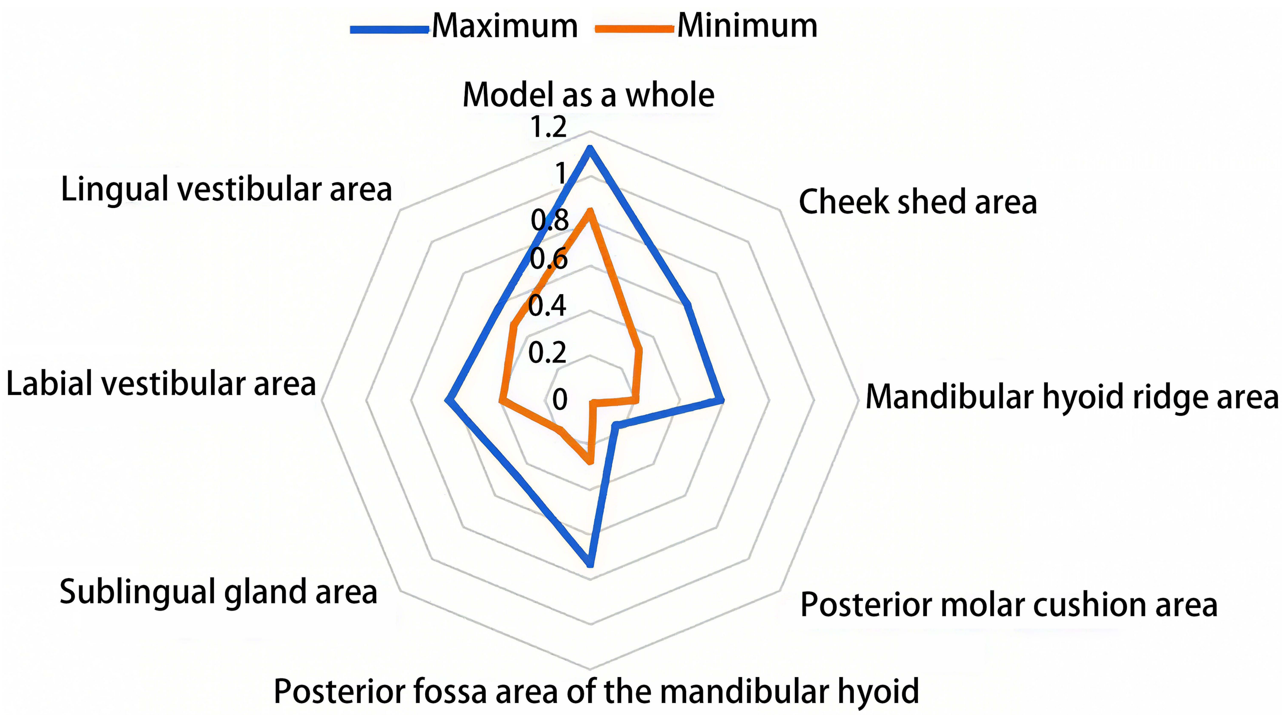

Figure 5 Extreme modification values observed in the initial and final models of the edentulous mandible for each functional area after best-fit matching.

complete dentures has not been fully explored and requires further research.[20,21] For example, Zhong et al compared the tissue surfaces of the mandibular complete-denture base made using functional impression techniques and anatomic impression techniques. Their study results showed that there were almost no differences in the alveolar ridge crest and the main load-bearing areas, but significant differences were found in the bilateral internal and external inclined ridges.[22] These results are very consistent with the results of this study.

This study has the following limitations: (1) This study is a single-center study, with a small number of included patients, resulting in reduced statistical power, increased uncertainty in the results, increased selection bias and measurement bias. (2) In the model matching aspect, a relatively traditional one-by-one matching and analysis method was used, which was inefficient. In future work, it is hoped to include more patients and train AI for more efficient matching and analysis, so as to conduct more case comparisons and reviews.

Conclusion

This study employed digital technology to analyze and compare the initial and final models of complete BPS dentures, revealing that the final BPS model provides a more accurate representation of mucosal movement, morphology, and the relative positioning of mandibular dentures under pressure, particularly in the posterior fossa of the mylohyoid muscle, submandibular gland region, and labial vestibule. These improvements are attributed to functional impression techniques that capture dynamic interactions between oral tissues and the denture base more effectively than traditional methods. Although the limited sample size necessitates further research, the findings highlight the potential of BPS techniques to enhance denture retention, stability, and fit. Continued advancements in complete denture fabrication, driven by digital tools and refined impression techniques, are expected to improve outcomes for edentulous patients and elevate the quality of clinical care.

Abbreviation

BPS, Bio-functional Prosthetic System.

Data Sharing Statement

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

Ethics Approval and Consent to Participate

This study was conducted with approval from the Ethics Committee of The Ninth Medical Center of PLA General Hospital (No. 20250507). This study was conducted in accordance with the declaration of Helsinki. Written informed consent was obtained from all participants.

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Disclosure

The authors declare that they have no conflicts of interest in this work.

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