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CLINICAL RESEARCH

Facial morphological changes following complete mouth rehabilitation with implant-supported fixed dental prostheses designed using digital virtual patients: A pilot study

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ABSTRACT

Statement of problem. Complete mouth rehabilitation with implant-supported fixed dental prostheses (ISFDPs) has become a common treatment option. The application of a virtual patient in complete mouth rehabilitation is believed to have considerable promise. However, studies reporting the facial morphological changes after complete mouth rehabilitation with ISFDPs designed using virtual patients are lacking.

Purpose. The purpose of this pilot clinical study was to evaluate the facial morphological changes after rehabilitation with complete arch ISFDPs designed using virtual patients.

Material and methods. Eight completely edentulous patients received implant surgery and a complete arch ISFDP. Facial scanning was performed at 3 time points: initial examination (FS1), after jaw relationship recording (FS2), and after prosthesis delivery (FS3). The ISFDPs were fabricated based on virtual patients constructed using FS2 data. FS1 was compared with FS3 to evaluate the facial morphological changes before and after complete mouth rehabilitation with an ISFDP. The root mean square (RMS) of the following segmented regions were recorded: right buccal, left buccal, right paranasal, left paranasal, upper lip, and lower lip. The linear deviation of the labrale superius and the changes in the nasolabial angle were also measured. The Kruskal-Wallis H test was used to test the difference in the morphological changes among the segmented facial regions (α=.05).

Results. Between FS1 and FS3, significantly more morphological change was found in the upper lip region [(3.23, 2.62/3.86) mm] than in the other perioral regions (P=.012). The lower thirds of the upper lip [(3.40, 2.54/4.22) mm] showed significantly more change than the middle [(1.97, 1.07/2.61) mm] and upper thirds [(1.13, 0.90/1.50) mm] (P<.001). The linear deviation of the labrale superius was (3.18, 2.53/3.60) mm. The change in nasolabial angle was (6.48, 4.00/9.51) degrees.

Conclusions. After complete mouth rehabilitation with an ISFDP designed using a virtual patient, the facial morphological change in the upper lip region was greater than in the other segmented facial regions. The lower thirds of the upper lip showed the greatest change. (J Prosthet Dent 2026;135:553-560)

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Clinical Implications

The application of a virtual patient and digital analysis software program offered benefits for the 3-dimensional evaluation of facial morphological changes after complete mouth rehabilitation.

Complete mouth rehabilitation with implant-supported fixed dental prostheses (ISFDPs) has become a common treatment option.[1–3] Previous studies have reported that a complete arch ISFDP showed favorable outcomes in terms of implant survival rate,[4] prosthesis survival rate,[5,6] and patient-reported outcome measures.[1] Multiple digital techniques have assisted in the implant placement,[7] impression making,[8–10] and framework fabrication[11] for a complete mouth rehabilitation with an ISFDP. However, evaluations of esthetics after rehabilitation with complete arch ISFDPs are lacking.

Edentulous patients have been reported to show an increased demand for both well-designed and functional complete arch ISFDPs.[12] Digital smile design (DSD) technology has become popular in esthetic designing for anterior restorations.[13] Although conventional DSD has been conducted based on 2-dimensional patient (2D) data, achieving successful complete mouth rehabilitation requires the harmonious integration of facial morphology, occlusal relationship, and prosthesis design, and providing sufficient information through 2D data is challenging. With the advancement of technology, various digital methods have been proposed for collecting the oral and maxillofacial morphology information of edentulous patients, such as cast scanning,[14] intraoral scanning,[15] and 3-dimensional (3D) facial scanning.[16] Applications of various 3D digital information in the clinical diagnosis, treatment planning, implant surgery, and restoration design have significantly improved the quality of clinical practice.[17]

As a noncontact and noninvasive technique, facial scanning can be integrated with various 3D datasets.[18] Previous studies have demonstrated that the 3D facial morphology data have been applied to various procedures, including the esthetic design of anterior restorations,[19] virtual tooth arrangement,[20] simulation of clinical evaluation of restorations,[21] fabrication of immediate complete dentures,[22] and the enhancement of communication regarding esthetic outcomes.[23] Therefore, the quantitative evaluation of the facial morphological changes after complete mouth rehabilitation may be achieved by importing the facial scanning data into digital analysis software programs.[24]

A virtual patient (VP) created by integrating various types of 3D digital data can provide guidance for complete mouth rehabilitation.[25] Based on a 3D virtual patient, restorations and implant surgeries can be digitally designed and planned before treatment using computer-aided design and computer-aided manufacture (CAD-CAM) technology.[26] Although the application of a virtual patient in complete mouth rehabilitation has been believed to have considerable promise,[27] to date, only concepts or techniques have been published. The facial morphological changes after complete mouth rehabilitation with ISFDPs designed using virtual patients need to be investigated.

The aim of this pilot study was to evaluate the facial morphological changes after complete mouth rehabilitation with ISFDPs designed using a virtual patient. The null hypothesis was that no difference would be found in facial morphology before and after rehabilitation with a complete arch ISFDP.

MATERIAL AND METHODS

This study was conducted in the Department of Prosthodontics, Peking University School and Hospital of Stomatology. The study was reviewed and approved by the Institutional Review Board of Peking University School and Hospital of Stomatology (Ethical approval No: PKUSSIRB-202057115). The study had been registered in the Chinese Clinical Trial Registry (ChiCTR) (ChiCTR2000038501) and was undertaken with the understanding and written consent of each participant and according to the World Medical Association Declaration of Helsinki (version 2013).

Participants who had a completely edentulous maxilla for at least 6 months and planned to receive a complete arch ISFDP were included. Each participant had a normal maxillomandibular relationship and did not require complex bone grafting surgery. Those who had local or systemic contraindications for implant surgery were excluded, as were those who smoked more than 10 cigarettes per day.

Treatment planning and rehabilitation procedures for each participant are outlined in the study flowchart (Fig. 1). During the first clinical appointment, facial scanning (FaceSCAN3D; 3D-Shape GmbH) was obtained with participants maintained in the rest position to record the 3D facial morphology before rehabilitation (FS1). After clinical examination, the digital planning of the implant placement was conducted as described previously.[28] Briefly, a cone beam computed tomography (VGI evo; NewTom) scan was carried out for each participant, who wore an anchor pin-supported radiographic template. Digital surgical planning (ORGANICAL Dental Implant v1.1.0.5; Organical CAD/CAM GmbH) and an interim prosthesis design (DentalCAD; exocad GmbH) were conducted based on these data. Implant (RC BL; Institut Straumann AG) placement was guided by an anchor pin-supported surgical template.

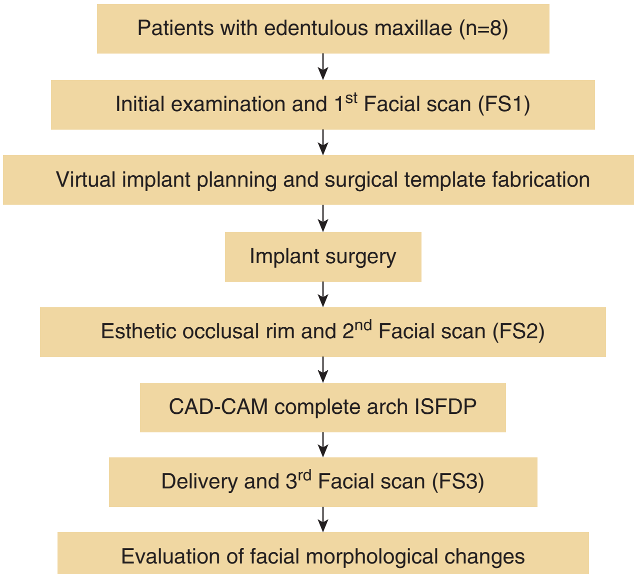

Figure 1. Study flowchart.

After implant osseointegration, screw-retained abutments (SRA abutments; Institut Straumann AG) were connected and a pick-up implant impression was made. A definitive cast was poured and digitized (D2000; 3Shape A/S). A wax occlusion rim with feature markers was made to record jaw relationship and esthetic parameters. The casts and a wax occlusion rim were 3D surface scanned (inEos X5; Dentsply Sirona, Inc). The second facial scanning (FS2) was obtained with each participant wearing a occlusion rim during 3 facial expressions: in rest position, smiling, and laughing. A virtual patient (VP) was constructed by integrating various 3D data in terms of intraoral scanning, cast scanning, and facial scanning (DentalCAD; exocad GmbH) (Fig. 2). An interim prosthesis was digitally designed based on the VP. According to intraoral and facial reference planes, a virtual arrangement of artificial teeth was completed. Occlusal contacts were digitally analyzed and adjusted to ensure the absence of occlusal interference. Data were transferred to a milling device (Organical Multi S; Organical CAD/CAM GmbH) for the fabrication of a definitive prosthesis. After delivery of a complete arch ISFDP, the third facial scan (FS3) was obtained with participants maintaining the rest position.

FS1 and FS3 data were imported into digital analysis software program (Geomagic Studio 12; 3D Systems, Inc) (Fig. 3). A local coordinate system was established for all facial scanning data by defining a coordinate origin at the contact point of maxillary incisor. The X-axis was parallel to a line connecting the left outer canthus point (OCL) to the right outer canthus point (OCR), with the leftward direction being positive. The Z-axis was parallel to the Camper line, and the direction toward the face was positive. The Y-axis was perpendicular to the XZ plane, with the upward direction being positive. All facial scanning data were superimposed using the interactive closest point (ICP) algorithm of the forehead regions. A root mean square (RMS) less than 0.5 mm was set as the standard for best fit alignment of the selected corresponding area.[29,30]

To evaluate the facial morphological changes following the complete mouth rehabilitation, FS1 data was superimposed on the FS3 data. Fourteen landmarks on a

Figure 2. Procedures of virtual patient construction and application. A, Wax occlusion rim with feature markers. B, Digitized casts and occlusion rim. C, Multisource data superimposition. D, Complete arch implant-supported fixed dental prosthesis designed using virtual patient.

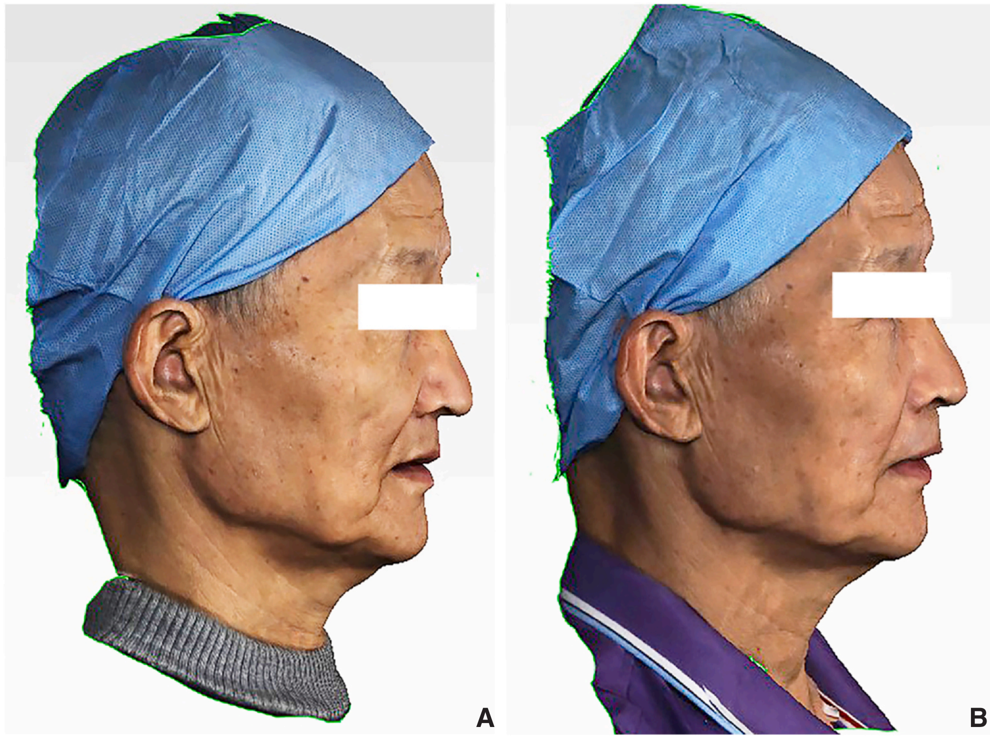

Figure 3. Facial scanning. A, Facial scanning before rehabilitation (FS1). B, Facial scanning after delivery (FS3).

3D facial model were selected (Table 1).[31] According to lines connecting these landmarks, a 3D face model was segmented into the following 6 regions: right buccal, left buccal, right paranasal, left paranasal, upper lip, and lower lip. For a better evaluation, the upper lip region was equally divided into 3 parts on the basis of a line connecting the subnasale (Sn) and labrale superius (Ls) (Fig. 4). After registration, the RMS of each region was recorded. The 3D coordinates of Ls in the FS1 and FS3 models were recorded independently. The nasolabial angles of the FS1 and FS3 models were quantified using a digital software program (Geomagic Qualify 12; 3D Systems, Inc) independently. A linear deviation of Ls and changes in nasolabial angles were measured (Fig. 5).

All these outcomes were measured 3 times, and the average value was calculated. Results were analyzed using a statistical software program (IBM SPSS Statistics, v27; IBM Corp). A Shapiro–Wilk test determined that some data conformed to a nonnormal distribution ($P<.05$). The Kruskal-Wallis H test was used to test the difference in facial morphological changes among the segmented facial regions ($\alpha=.05$).

RESULTS

Eight participants (3 women and 5 men) with a mean age of 50.8 years were enrolled. Seventy-six implants

Table 1. Landmarks used

No.	Abbr	Landmarks	Definition
1	Tr	Tragion right	Point of transition from base of ear wheel foot to skin on cranial side
2	Tl	Tragion left	Point of transition from base of ear wheel foot to skin on cranial side
3	Orr	Orbitale right	Most inferior point on right inferior orbital rim
4	Orl	Orbitale left	Most inferior point on left inferior orbital rim
5	Alr	Alare right	Most lateral point on right alar contour
6	All	Alare left	Most lateral point on left alar contour
7	Pn	Pronasale	Most anterior midpoint of nasal tip
8	Sn	Subnasale	Midpoint on nasolabial soft tissue contour between columella crest and upper lip
9	Ls	Labrale superius	Midpoint of upper vermillion of upper lip
10	Chr	Cheilion right	Point located at right labial commissure
11	Chl	Cheilion left	Point located at left labial commissure
12	Gor	Gonion right	Most lateral point on right mandibular angle
13	Gol	Gonion left	Most lateral point on left mandibular angle
14	Pog	Soft tissue pogonion	Most anterior midpoint of chin

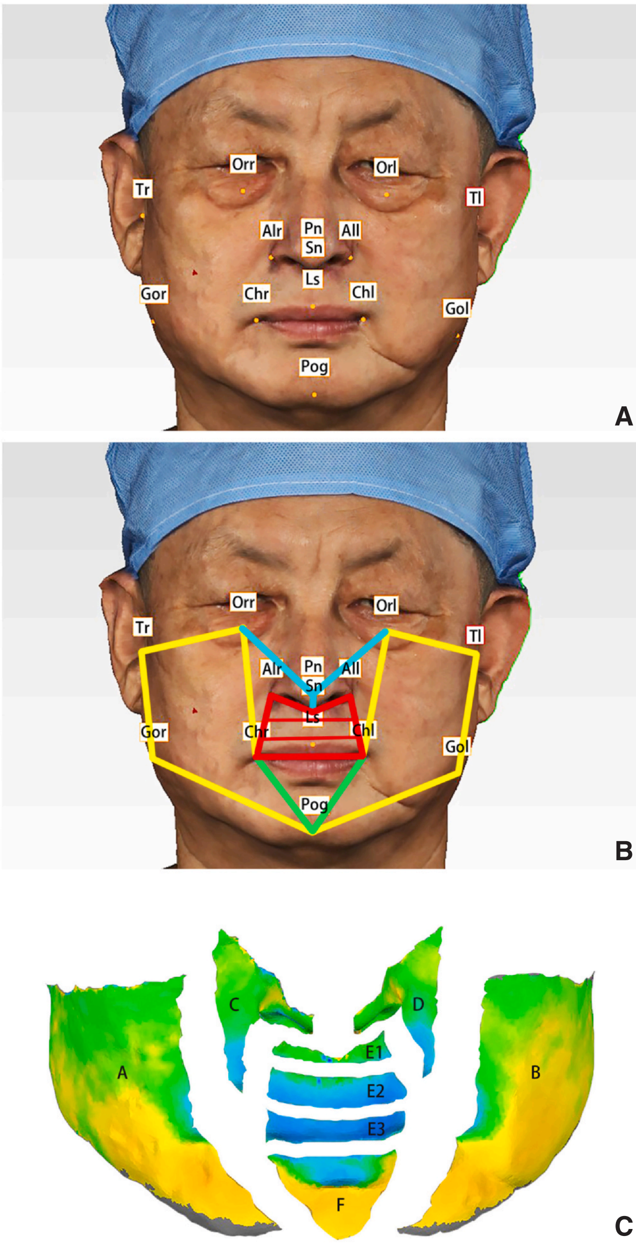

Figure 4. Evaluation of facial morphological changes between FS1 and FS3. A, Landmarks on 3-dimensional facial cast. B, Segmented regions of face and upper lip region. C, Morphological changes of segmented regions: A, right buccal; B, left buccal; C, right paranasal; D, left paranasal; E1, upper thirds of upper lip; E2, middle thirds of upper lip; E3, lower thirds of upper lip; F, lower lip.

were placed using anchor pin-supported surgical templates, and 11 complete arch ISFDPs (8 maxillary and 3 mandibular) were fabricated using virtual patients.

Between FS1 and FS3, the RMS of the total facial morphology was 2.04, 1.78/2.24 mm. Morphological changes in the upper lip region (3.23, 2.62/3.86 mm) were significantly greater than those in the other regions (P=.012). Biparanasal regions showed the fewest changes following the complete mouth rehabilitation (Table 2). The upper lip region was further segmented into 3 parts (Table 3). The lower thirds of the upper lip (3.40, 2.54/4.22 mm) showed significantly greater changes than the middle (1.97, 1.07/2.61 mm) and upper thirds (1.13, 0.90/1.50 mm) (P<.001).

Between FS1 and FS3, the linear deviation of Ls was 3.18 (2.53/3.60) mm. The linear deviation of Ls was (0.07, −0.66/0.40) mm in the X-axis direction, (0.82, 0.82/0.89) mm in the Y-axis direction, and (2.69, 2.60/2.32) mm in the Z-axis direction. The average change of nasolabial angle was 6.48, 4.00/9.51 degrees (Table 4).

DISCUSSION

The null hypothesis that no difference would be found in facial morphology before and after rehabilitation with a complete arch ISFDP was rejected. The greatest facial morphological change was found in the upper lip region after complete mouth rehabilitation with an ISFDP designed using a virtual patient. The RMS of the lower thirds of the upper lip region was (3.40, 2.54/4.22) mm. The average change in the nasolabial angle was 6.48, 4.00/9.51 degrees. The applications of a virtual patient and digital analysis offered benefits for the 3D assessments of facial morphological changes after a complete mouth rehabilitation.

A virtual patient constructed with facial scanning data including a wax occlusion rim provided guidance for implant placement and an interim prosthesis design in this study. The feasibility of the digital implant planning and fabrication of an immediate restoration for a complete mouth rehabilitation using a wax occlusion rim with feature landmarks has been previously reported.[28] Compared with FS2, the average morphological change of FS3 was less than 2 mm, which confirmed the advantage of using a virtual patient to predict postoperative soft tissue.[32]

Errors accumulated between the virtual design and the definitive restorations and were attributed to data acquisition, data fusion, and data analysis. To minimize errors, advanced devices were used to construct a virtual patient. The accuracy of a structured light scanning system used for facial data acquisition has been reported to be about 0.2 mm.[33] A laboratory scanner with an accuracy of approximately 0.026 mm was used in this study.[34] The construction and alignment algorithms of a virtual patient may introduce an error of up to 0.5 mm.[35] In addition, during the CAD-CAM process, errors may result from the manual design by a technician and the computer numerical control milling.

After complete mouth rehabilitations, the upper lip region showed the greatest morphological changes, followed by the lower lip region. A previous study has

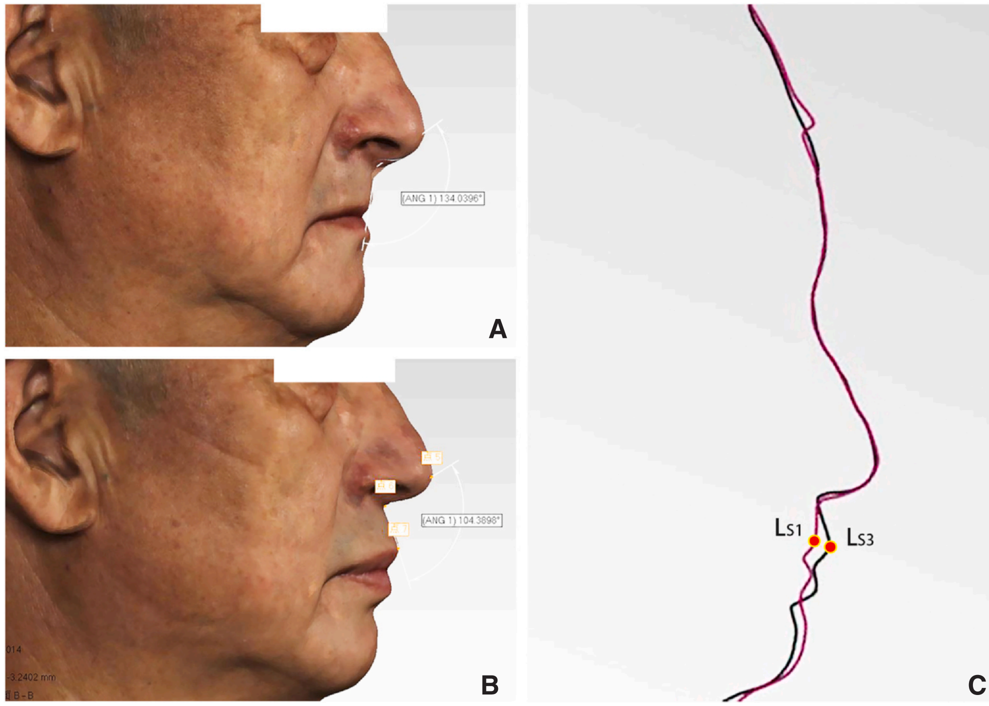

Figure 5. Changes of nasolabial angle and linear deviation of Ls between FS1 and FS3. A, Nasolabial angle before rehabilitation. B, Nasolabial angle after rehabilitation. C, Positions of Ls before and after rehabilitation.

Table 2. Morphological changes between FS1 and FS3 (RMS, mm)

Segmented regions	Median (Q_{25}/Q_{75})	Min	Max
Right buccal	1.57 (0.95/2.12)	0.78	4.20
Left buccal	2.26 (1.34/2.56)	1.21	4.47
Right paranasal	1.93 (1.25/2.18)	1.06	2.42
Left paranasal	1.50 (1.37/1.71)	0.85	1.77
Upper lip	3.23 (2.62/3.86)	2.34	4.13
Lower lip	2.75 (1.01/3.56)	0.55	4.31
Total	2.04 (1.78/2.24)	1.15	3.86

Table 3. Morphological changes of upper lip region between FS1 and FS3 (RMS, mm)

Upper lip	Median (Q_{25}/Q_{75})	Min	Max
Upper thirds	1.13 (0.90/1.50)	0.84	1.87
Middle thirds	1.97 (1.07/2.61)	0.77	2.82
Lower thirds	3.40 (2.54/4.22)	2.31	4.36

Table 4. Linear deviation of labrale superius and change in nasolabial angle between FS1 and FS3

	Median (Q_{25}/Q_{75})	Min	Max
Linear deviation of Ls (mm)	3.18 (2.53/3.60)	1.69	4.66
Change of nasolabial angle (degree)	6.48 (4.00/9.51)	2.04	29.65

reported the linear equation between upper lip changes and the positions of the anterior part of complete arch ISFDPs.[29] The 3D lip profile after rehabilitation could be predicted by using the Dolphin software program. Implant placement and complete mouth rehabilitation with an ISFDP guided by the predicted 3D facial profile was described in a clinical report.[36] The analysis of the facial morphological changes of specific segmented regions provided more meaningful information for clinical practice.[33] Unlike in orthodontic and orthognathic treatment, the fullness of lips and changes in the paranasal and buccal regions were focused upon during complete mouth rehabilitations. Therefore, the principle of the segmented regions was modified for this study.

After the delivery of a complete arch ISFDP, the position and morphology of the upper lip was found to change significantly. The lower thirds of the upper lip region achieved sufficient support, while the upper thirds showed minimal changes. As it is difficult to reconstruct soft tissue morphology for patients with severe residue alveolar resorption using a flangeless fixed restoration, a removable overdenture is appropriate to improve esthetics. The position of Ls changed mainly in the sagittal-forward and vertical direction, with a total value of 3.09 ±0.93 mm, consistent with a previous study.[28] The mean reduction of the nasolabial angle was about 9.17 degrees after complete mouth rehabilitation with an ISFDP in this study. A previous study reported that participants provided with a conventional complete denture had a reduction of about 18 degrees in the nasolabial angle.[37] Two other indicators contributing to the decision between an implant-supported fixed dental prosthesis and an implant-supported overdenture are the angulation of the artificial gingival and prosthetic profile.[38]

Limitations of this study included the restricted availability of participants undergoing complete arch ISFDPs and a long treatment timeline, resulting in a cohort of only 8 participants who were provided with definitive rehabilitation in this pilot study. This small sample size is a major limitation, which may have reduced the statistical power of this study and restricted the generalizability of the findings to broader populations. Measurement errors in soft tissue landmarks may disproportionately affect outcomes in this small cohort. Another limitation of this study was that the results are applicable only to participants without severe maxillary osteotomy surgery. The severity of residual alveolar ridge resorption demonstrated a significant correlation with morphological changes in soft tissue. A larger cohort study is needed for further subgroup analysis. The application of complete mouth rehabilitation with ISFDPs designed using virtual patients for participants with insufficient bone requires further investigation.

CONCLUSIONS

Based on the findings of this pilot study, the following conclusions were drawn:

1. After complete mouth rehabilitation with an ISFDP designed using a virtual patient, the facial morphological change in the upper lip region was greater than in other segmented regions.
2. The lower thirds of the upper lip region showed the greatest change.

PATIENT CONSENT

Written informed consents were obtained from patients prior to enrollment and for the publication of this study.

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CRediT authorship contribution statement
Danni Guo: Data curation, Formal analysis, Investigation, Writing - original draft. **Shenghan Gao**: Investigation, Visualization, Data curation, Software. **Shaoxia Pan**: Conceptualization, Funding acquisition, Resources, Investigation, Methodology, Project administration, Writing - review and editing. **Yongsheng Zhou**: Funding acquisition, Resources, Supervision, Validation, Writing - review and editing.

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