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Original Article

Assessment of facial symmetry by three-dimensional stereophotogrammetry after mandibular reconstruction: A comparison with subjective assessment

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ABSTRACT

Introduction: The assessment of facial symmetry, after mandibular reconstruction, currently relies on subjective esthetic assessment by an evaluator. The present study aimed to compare conventional subjective assessment with quantitative evaluation by three-dimensional (3D) stereophotogrammetry of facial cosmetic symmetry.
Methods: This retrospective study enrolled 20 patients who underwent mandibular reconstruction with free fibula flap after segmental resection between 2014 and 2018. Subjective assessments were performed by seven clinicians at 6–12 months after surgery. Simultaneously, lower face symmetry was measured by 3D stereophotogrammetry with the VECTRA H1 system and recorded as the root mean square deviation (RMSD). Data from the subjective and quantitative evaluations were compared using Spearman's rank correlation coefficient.
Results: The results showed that subjective assessments were strongly and negatively correlated with RMSD ($P = 0.00000128$). This confirmed that RMSD, obtained by 3D stereophotogrammetry, reflected the subjective assessment of symmetry in our cohort.
Conclusions: Three-dimensional stereophotogrammetry of facial cosmetic symmetry will be an available quantitative method for patients with head and neck cancer after mandibular reconstruction.

1. Introduction

Mandibular reconstruction after segmental mandibulectomy for benign and malignant tumors, osteomyelitis, or osteoradionecrosis of the mandible remains a surgical challenge. The goals of reconstruction are not only functional (swallowing and speaking), but also esthetic (satisfactory appearance). However, although esthetic outcomes are important in mandibular reconstruction [1–3], benchmarks for measuring these outcomes are currently insufficient. This is further complicated by a lack of reports on the assessment of esthetic outcomes after mandibular reconstruction [1–5]. Moreover, the available reports tend to have been limited to subjective assessments using visual analog scoring scales [1–3] and have recommended multiple assessments by different evaluators [5]. These methods are complex and produce inconsistent results among evaluators [5,6]. Therefore, rather than just subjective assessment, there is a need for objective evaluation using quantitative techniques to provide greater efficiency and consistency. One approach may be to use three-dimensional (3D) analysis. Advanced anthropometric survey by 3D stereophotogrammetry is used for screening head and neck diseases such as cleft lip and palate [7–9], orthognathic abnormalities [10,11], facial palsy [12] and hemifacial microsomia [13]. However, to the best of our knowledge, to date, the validity of using 3D images to assess esthetic outcomes has not been evaluated for mandibular reconstruction.

Therefore, the present study compared objective 3D stereophotogrammetry with conventional subjective assessment to

Abbreviations: BCT, Breast Conserving Therapy; ICP, Iterative Closest Point; RMSD, Root Mean Square Deviation.

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determine the suitability of using 3D images for esthetic assessments of head and neck cancer.

2. Materials and methods

2.1. Patients

Patients were eligible to participate in this retrospective study if they had undergone mandibular reconstruction with microvascular free fibula flaps at the Department of Oral and Maxillofacial Surgery, Nara Medical University Hospital (Nara, Japan), between January 2014 and May 2018. Patients who had preoperative trauma of the oral and maxillofacial regions and reoperation for recurrence during follow-up were excluded ($n = 5$). Mandibular reconstruction was performed by the same surgical team. All the patients underwent computer-aided surgical simulation using 3D modeling of the mandible [14]. A free fibula flap was prefabricated to fit at the defect site to match the mandible's original contour. Follow-up was conducted for 6–12 months after the reconstructive surgery.

Ethical approval was granted by the Institutional Review Board of Nara Medical University Hospital (Reference 2185), which required that we presented the research plan and right to opt out on our hospital's homepage. This study did not require patient consent because of its retrospective nature, and therefore, we published the research plan and guaranteed an opt-out opportunity by the homepage of our hospital according to the instruction of the institutional review board.

2.2. Subjective assessment of facial asymmetry

Subjective assessments were separately performed by seven oral and maxillofacial clinicians using photographs. Valuers included a member of the surgical team ($n = 1$), clinicians specialized in head and neck cancer ($n = 2$), clinicians not specialized in head and neck cancer ($n = 2$), and clinicians of other department ($n = 2$). These valuers had clinical experiences of > 20 years ($n = 2$), > 10 years ($n = 3$), and ≤ 10 years ($n = 2$).

Assessments were performed according to the following 4-point classification by Katsuragi et al. [1] with 4 ("excellent") indicating a symmetrical mandibular and cheek outline; 3 ("good") indicating slight asymmetry, such as depressed cheeks or lip deformities; 2 ("fair") indicating visible facial scars or an asymmetrical soft tissue outline; and 1 ("poor") indicating an asymmetrical mandibular outline, an exposed skin island with poor color match, and any other defects.

2.3. Objective assessment of facial symmetry

2.3.1. Image acquisition and creation of a mirrored three-dimensional photograph

Surface images were captured by the same clinician using a portable stereophotogrammetry device (VECTRA H1; Canfield Imaging, Parsippany, NJ, USA) according to the product manufacturer's instructions. We modified the method, proposed by Verhoeven et al. [4], to quantify soft tissue facial asymmetry. First, the neck and hair were removed from the images to exclude the confounding regions using the VECTRA software (Canfield Imaging). Facial landmarks were digitally marked on each acquired image to delimit the portions of the face for evaluation. Four soft tissue landmarks were manually identified: left exocanthion (ExL), right exocanthion (ExR), subnasale (Sn), and sellion (Se). A transversal plane was then placed through three of these points (ExL, ExR and Se). The coronal plane was constructed perpendicular to the transversal plane through ExL and ExR. The facial midline sagittal plane was constructed perpendicular to the coronal plane through Se and Sn. The mirrored surface was created using the data for the facial midline sagittal plane (Fig. 1). To achieve area-based registration, the sum of the squared shortest distances from one surface to another was used, which is also known as the iterative closest point (ICP) algorithm. The forehead, upper nasal dorsum, and zygoma surfaces of the original image were selected as regions of interest, and registration with the mirror image was performed according to the ICP algorithm.

2.3.2. Setup for the region of interest affected by surgery

Surface data from the surgery-affected and mirrored unaffected sides were separated in the lower half of the facial image for further analysis. The boundary of the lower half of the face was the Frankfurt horizontal plane; the mandibular plane was at the bottom of the image, such that the neck was not visible; and for the posterior view, the ramus plane was used for the image sides (Fig. 2). The sagittal plane of the midline was used to isolate the surface data of the unoperated side in the mirror image from the surface data of the operated side.

2.3.3. Distance measurement with surface data

The minimized distance map was created using the VECTRA software, with the distances between corresponding points on 3D photographs illustrated on the map (Fig. 3). Finally, the root mean square deviation (RMSD) between the points on the 3D photograph surfaces was calculated to measure facial asymmetry, which is common with 3D stereophotogrammetry [10,12,15,16].

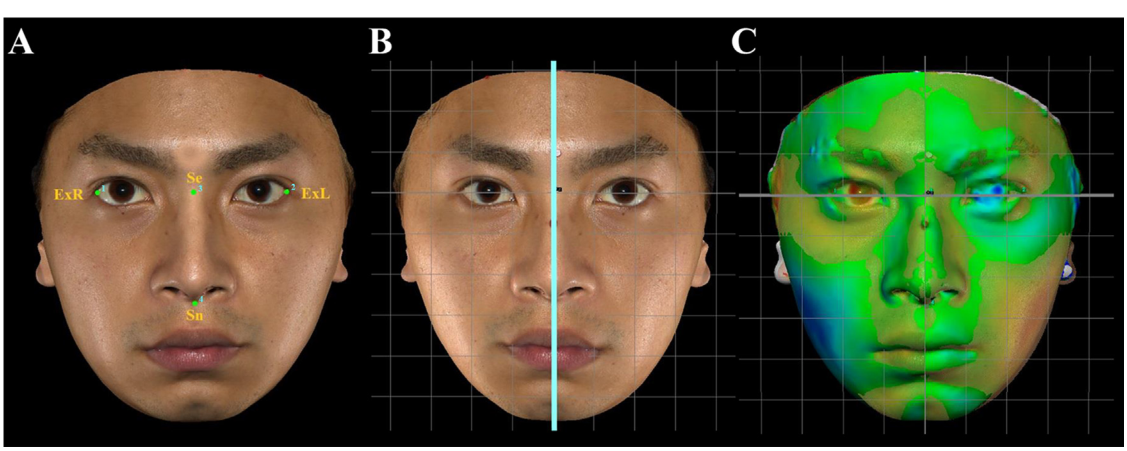

Fig. 1. The photograph, landmark allocation, and color-coded mapping. A. The original three-dimensional (3D) photograph used to create the sagittal mirror plane. B. Creation of a mirrored 3D photograph. C. Color-coded maps for the local distances between the original and mirrored 3D photograph. The subject of the photo is one of the authors (Dr. Masato Nakagawa). ExR: right exocanthion; ExL: left exocanthion; Sn: subnasale; Se: sellion.

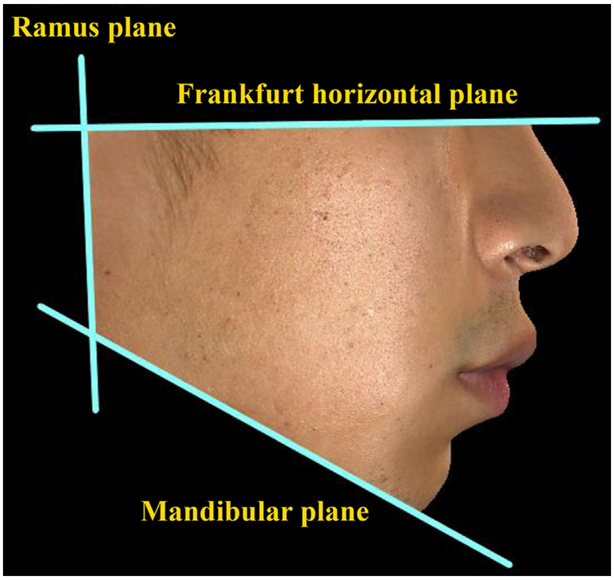

Fig. 2. Evaluation of the lower half of the face as the region clearly affected by surgery. The lower half of the face is the area bounded by the Frankfurt horizontal plane, mandibular plane and ramus plane.

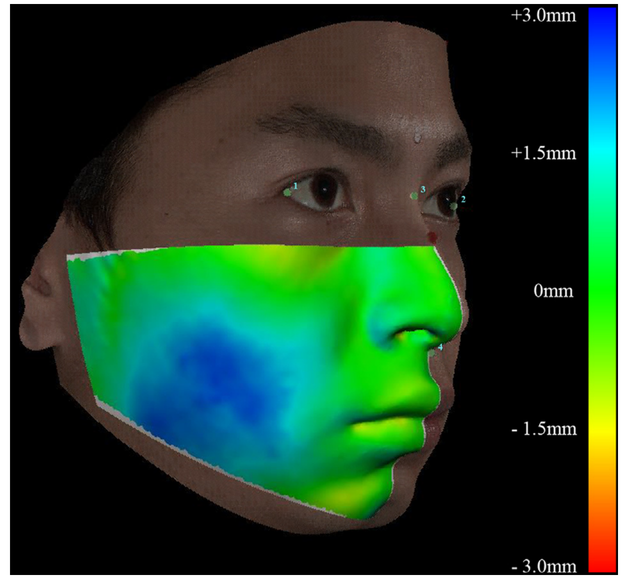

Fig. 3. Objective evaluation of asymmetry in the lower half of the face. The areas evaluated are isolated by the Frankfurt horizontal plane, mandibular plane, ramus plane, and facial midline sagittal plane. Color-coded maps show the local distances between the reconstructed and mirrored/unoperated sides. Positive values are indicated in blue and negative in red. The original 3D photograph is superimposed for this subject.

2.4. Statistical analysis and validation

First, we tested interobserver reliability among the seven clinicians, which was verified by Fleiss' kappa test. Second, we compared the relationship between RMSD and the average score of the seven participating clinicians using Spearman's rank correlation coefficient (r). We considered statistical significance for an α level of 0.05. All statistical analyses were performed with R (R Foundation for Statistical Computing, Vienna) and EZR software (Saitama Medical Center, Jichi Medical University, Saitama, Japan).

3. Results

A total of 20 patients (patients 1–20) were enrolled in this study, as summarized in Table 1. Data for the subjective and objective assessments are shown in Table 2. In the cohort, two patients had a history of radiation therapy. In addition, five patients received postoperative chemoradiotherapy (Table 1). No external skin island patients were included in this cohort.

The median subjective assessment score was 3.14 (range: 1.57–4.00), whereas the median RMSD was 2.59 (range: 1.09–6.74; Table 2). Notably, all the clinicians who performed subjective assessments assigned the same score in only three patients (15%). In 14 patients (70%), evaluations differed by two scores, and in the remaining three patients (15%), evaluations differed by three scores (Fig. 4). The inter-rater agreement (Fleiss' kappa) was 0.42 for the subjective assessments. Finally, we demonstrated a strong negative correlation between the average subjective assessment score and the average RMSD value ($r = -0.858$, $P = 0.00000128$; Fig. 5).

Table 1
Patient data.

Patient	Sex	Age (years)	BMI (kg/m^2)	Diagnosis	TNM (stage)	Jewer's classification	Bony segments (fibula)	Radiation
1	F	41	21.6	SCC	T4aN0M0 (IVa)	L	2[a]	–
2	M	62	19.5	SCC	T4aN2bM0 (IVa)	LC	3[a]	–
3	M	66	21.1	SCC	T4aN0M0 (IVa)	L	3[a]	–
4	F	71	23.7	SCC	T4aN1M0 (IVa)	L	2	–
5	F	80	23.8	SCC	T4aN2bM0 (IVa)	L	1	–
6	F	80	20.9	SCC	T4aN2bM0 (IVa)	L	2	–
7	M	52	25.3	SCC	T4aN1M0 (IVa)	L	2[a]	60 Gy
8	M	73	18.3	SCC	T4aN2bM0 (IVa)	L	3	60 Gy
9	M	79	22.3	SCC	T2N2bM0 (IVa)	L	2	50 Gy
10	M	75	22.0	SCC	T4aN2bM0 (IVa)	LC	2	60 Gy
11	F	81	19.9	SCC	T4aN2bM0 (IVa)	H	2	–
12	F	68	18.1	ORN	–	L	2	66 Gy
13	M	67	19.1	SCC	T3N2bM0 (IVa)	L	2[a]	60 Gy
14	M	70	23.5	SCC	T4aN2bM0 (IVa)	L	3	–
15	M	73	23.5	ORN	–	L	2	70 Gy
16	F	59	18.8	SCC	T4aN1M0 (IVa)	L	1	–
17	M	44	31.4	SCC	T4aN1M0 (IVa)	LC	4[a]	–
18	M	62	25.2	SCC	T2N1M0 (III)	L	1	–
19	M	71	23.3	SCC	T4aN1M0 (IVa)	L	1	–
20	M	61	25.5	SCC	T3N2bM0 (IVa)	L	3[a]	–

ORN: osteoradionecrosis; SCC: squamous cell carcinoma; BMI: body mass index; C: central defects (affecting the entire anterior segment, including two canines and four incisors); H: hemi-mandibular defects (affecting any length of the lateral segment, including the condyle); L: lateral defects (affecting the lateral segment but excluding the condyle); F: female; M: male.
[a] Double-barrel.

Table 2
Subjective and objective evaluations of facial symmetry among 20 patients after mandibular reconstruction.

Patient	Timing of the evaluation (postoperative month)	Number of clinicians (%)					RMSD (mm)
		Poor (score: 1) *n* (%)	Fair (score: 2) *n* (%)	Good (score: 3) *n* (%)	Excellent (score: 4) *n* (%)	Average Score	
1	11 M	0 (0%)	6 (85.7%)	1 (14.3%)	0 (0%)	2.14	4.28
2	11 M	0 (0%)	0 (0%)	0 (0%)	7 (100%)	4.00	1.50
3	8 M	0 (0%)	4 (57.1%)	3 (42.9%)	0 (0%)	2.43	3.01
4	7 M	0 (0%)	0 (0%)	6 (85.7%)	1 (14.3%)	3.14	2.50
5	12 M	0 (0%)	0 (0%)	0 (0%)	7 (100%)	4.00	1.34
6	7 M	0 (0%)	0 (0%)	6 (85.7%)	1 (14.3%)	3.14	1.68
7	10 M	0 (0%)	4 (57.1%)	3 (42.9%)	0 (0%)	2.43	5.65
8	9 M	1 (14.3%)	6 (85.7%)	0 (0%)	0 (0%)	1.86	6.74
9	10 M	1 (14.3%)	3 (42.9%)	3 (42.9%)	0 (0%)	2.29	4.00
10	10 M	3 (42.9%)	4 (57.1%)	0 (0%)	0 (0%)	1.57	5.52
11	9 M	2 (28.6%)	5 (71.4%)	0 (0%)	0 (0%)	1.71	4.25
12	9 M	0 (0%)	0 (0%)	3 (42.9%)	4 (57.1%)	3.57	1.99
13	7 M	0 (0%)	0 (0%)	3 (42.9%)	4 (57.1%)	3.57	2.24
14	10 M	0 (0%)	5 (71.4%)	2 (28.6%)	0 (0%)	2.29	3.65
15	12 M	0 (0%)	0 (0%)	5 (71.4%)	2 (28.6%)	3.29	1.93
16	6 M	0 (0%)	0 (0%)	0 (0%)	7 (100%)	4.00	1.09
17	12 M	0 (0%)	0 (0%)	1 (14.3%)	6 (85.7%)	3.86	2.68
18	9 M	0 (0%)	1 (14.3%)	4 (57.1%)	2 (28.6%)	3.14	1.59
19	12 M	0 (0%)	1 (14.3%)	4 (57.1%)	2 (28.6%)	3.14	3.42
20	12 M	0 (0%)	0 (0%)	1 (14.3%)	6 (85.7%)	3.86	1.79

RMSD: root mean square deviation. Objective assessment was performed by three-dimensional stereophotogrammetry

4. Discussion

Poor esthetic appearance after mandibular reconstruction can adversely affect the quality of a patient's life [17]. In head and neck cancer, subjective cosmetic assessment using visual analog scoring scales, as proposed by Katsuragi et al. [1], has been used for postoperative evaluation [1–3]. In this study, seven clinicians participated to reduce the variance among evaluators, and we showed moderate inter-rater agreement (Fleiss' kappa 0.42). The subjective score completely matched in three patients (patients 2, 5, and 16), with excellent subjective assessment scores and small RMSD values (1.50, 1.34, and 1.09 mm, respectively), which were the smallest among all the RMSD values. In contrast, the subjective assessment was relatively good for patient 17 (average score 3.87), which was matched in six clinicians as excellent, whereas RMSD showed a relatively large value (2.68 mm). The physical characteristics of this patient 17, that is, being obese with a round face, may have contributed to the result. In another three patients (patients 9, 18, and 19), subjective assessment was as wide as three grades (average scores 2.29, 3.14, and 3.14, respectively), with no uniformity

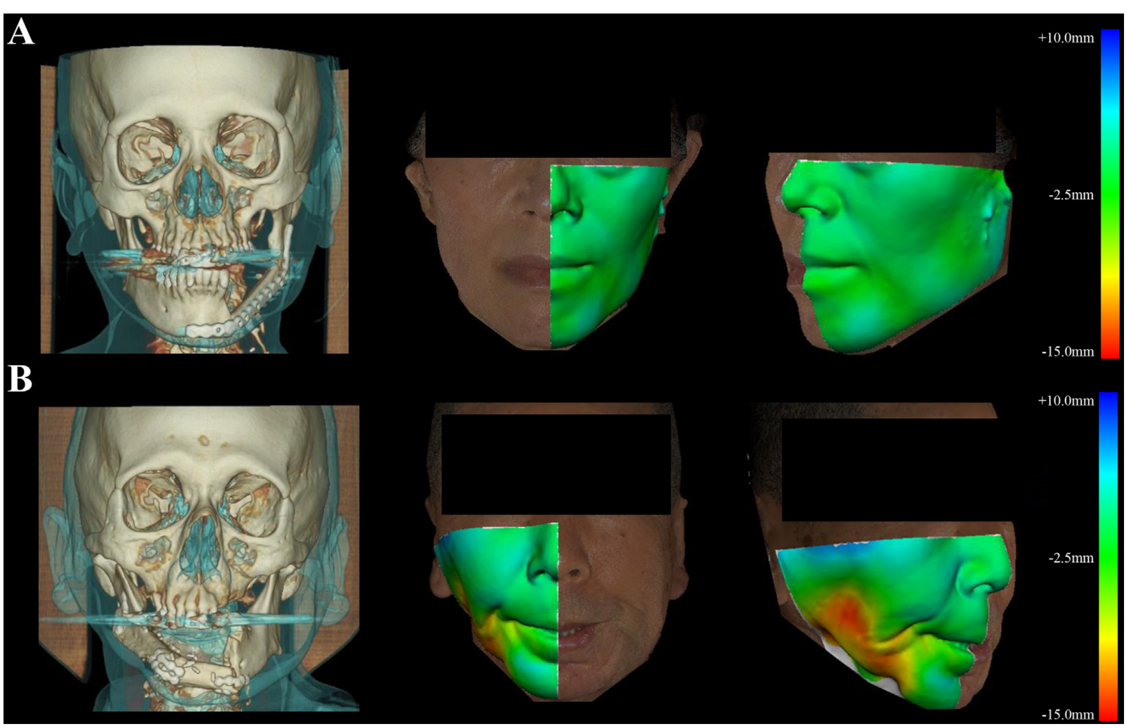

Fig. 4. Showing postoperative 3D-CT and color-coded maps of the patient. A. Patient 16 in Table 2 is the subject. Computed tomography scan and color-coded maps of the patient 9 months after reconstruction. The subjective assessment score was 4.00 and root mean square deviation (RMSD) was 1.09 mm. B. Patient 10 in Table 2 is the subject. Computed tomography scan and color-coded maps of the patient 12 months after reconstruction. The subjective assessment score was 1.57 and RMSD was 5.52 mm.

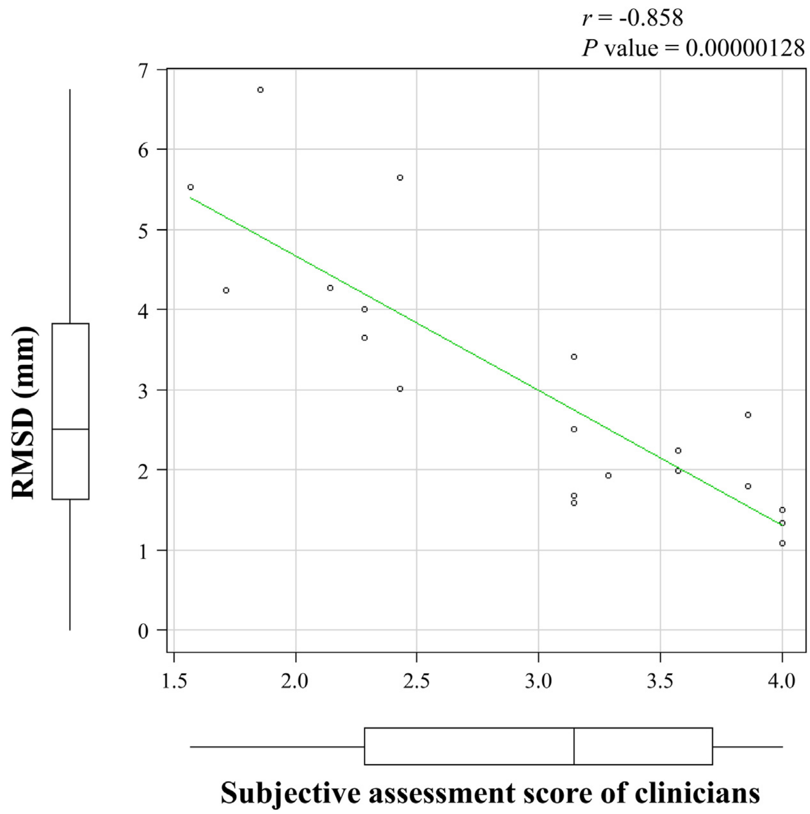

Fig. 5. Correlation between subjective score and objective RMSD. RMSD: root mean square deviation.

in RMSD (4.00, 1.59, and 3.42 mm, respectively). This inconsistent trend in RMSD may relate to the partial element of concavity or convexity. For example, it was observed that patient 18 had depressed cheeks, possibly because of the postoperative infection. RMSD (1.59 mm) indicated that the depressed area was small, although esthetic outcomes were subjectively judged with a lower score. This is one of the limitations of this technology because small but important concavity or convexity reflects the light and the light/shadow created tends to emphasize human eye deformation. It is known that different professionals and patients may evaluate cases differently [5]. The evaluators in this study were oral surgeons; this may be a limitation. Nevertheless, we demonstrated that there was a strong inverse correlation between RMSD and subjective assessment. RMSD values are often used preoperatively in breast surgery to simulate breast symmetry in breast augmentation or cancer treatment [15] or to be used as surrogate markers of esthetic outcomes [16].

During the past few decades, new 3D image acquisition systems have revolutionized the procedures for assessing anthropometric surveys, including facial structure [4,7–13,18–20]. In head and neck cancer, 3D analysis has already been used for computer-aided simulation of surgical techniques [14,21,22]. The accuracy of results enables comparison of the original and reconstructed mandible to evaluate operation outcomes with hard tissues [23]. Several techniques have been used to analyze facial features in 3D, including laser scanning [24], computed tomography [25] and cone-beam computed tomography [26]. Compared with these techniques, stereographic surveying is not only safer and lacks exposure to radiation [27] but also uses compact and portable equipment that is accurate, easy and quick to use [28]. The method is, therefore, well suited to clinical settings when monitoring the postoperative course after free flap reconstruction in head and neck cancer, wherein the flap volume changes over time and repeated measures are often needed [29].

A soft tissue prediction program has already been practically applied for orthognathic surgery [30], but not for mandibular reconstruction. Moreover, soft tissue prediction by a computer-aided planning system for mandibular reconstruction is expected in the near future. Quantitative and consistent objective evaluation, including the dynamical measuring system or Motion Capture technology, in the future should help us to compare operative outcomes among patients and observe postoperative changes. To the best of our knowledge, this is the first study to assess postoperative soft tissue outcomes using an objective 3D method in comparison with a best practice approach to subjective assessments. To conclude, we introduced and verified the efficacy of a new advanced method for objectively quantifying facial asymmetry after mandibular reconstruction. Our data indicated that RMSD measured by 3D stereophotogrammetry could be a supportive cosmetic evaluation. The present study was limited by a small sample size; therefore, further studies are warranted to confirm the significance of this observation.

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Disclosure of interest

The authors declare that they have no competing interest.

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