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Systematizing mandibular reconstruction using the resin frame method

Junichi Hayasaka, Shunji Sarukawa, Hiroto Itoh, Yoshiaki Takai, Mikio Kusama, Yoshiyuki Mori, Akitoshi Katsumata

ABSTRACT

Aims: Oral tumors are the most frequent diseases that lead to mandibular defects, but because they are so rare, it is difficult to obtain the necessary large capital investment to establish and introduce a mandibular reconstruction system. Therefore, we developed the Resin Frame method within the current facilities that objectively increases mandibular reproducibility without requiring advanced techniques. Methods: Subjects comprised 25 patients who underwent mandibular reconstruction by the resin frame method in the Department of Dentistry, Oral and Maxillofacial Surgery at Jichi Medical University Hospital between October 2013 and August 2015, and 25 patients who underwent the mandibular reconstruction by the conventional method between September 2007 and November 2011. All mandibles were reconstructed using fibula or iliac bones with a reconstruction plate. The computed tomography (CT) Digital Imaging and Communications in Medicine (DICOM) data before and after the operation were saved. Then, the layer function was used to fuse the pre- and postoperative CT images. Based on measured area, the concordance rate that is matching percentages between pre- and postoperative mandibles were calculated. We evaluated the difference between the concordance rate of the Resin Frame method and the conventional method of mandibular reconstruction. Results: Concordance rates for the resin frame method and conventional surgery were 75.09±6.09% and 67.39±13.44%, respectively, showing a significant difference (p=0.032, p<0.05). Conclusion: The resin frame method represents a mandibular reconstruction system that increases reproduction accuracy and can be implemented at current facilities using simple, objective techniques.

Keywords: Concordance rate, Mandibular reconstruction, Resin frame method, Reproducibility

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INTRODUCTION

Conventionally, mandibular reconstruction lacked objective simulations and depended largely on the subjective judgment of the surgeon [1–7].

The conventional method used to position the residual mandible uses a metal repositioning plate [8]. This method is excellent for conserving the position of residual mandible that has not been resected, but when the defect (reconstructed portion) is extensive, interference commonly occurs between the repositioning plate and the plate used to fix grafted bone. Furthermore, due to the subjective nature of the procedure, placement of grafted bone relies heavily on the technical expertise and experience of the surgeon, resulting in unstable reproducibility of the reconstructed mandible. Furthermore, repositioning plates are quite expensive [9].

To address these problems, we developed the resin frame method to objectively systematize the mandibular reconstruction procedure and increase its reproducibility without requiring a large-scale capital investment or advanced techniques that need expensive machine parts and software.

MATERIALS AND METHODS

Subjects

We conducted a retrospective study of 50 patients who underwent free-flap mandibular reconstruction following partial mandibulectomy at the Department of Dental Surgery, Jichi Medical University Hospital, from September 2007 to August 2015. Patients were categorized into the conventional method (n=25) and resin frame method (n=25) groups, depending on the method of reconstruction they underwent. Patients <18 years and those who underwent plate mandibular reconstruction only, were excluded. We examined the differences in age, sex, disease, site of mandibular defect, source of bone graft, graft bone fixation material, and concordance rate, between the two groups.

This study was approved by the ethics committee of Jichi Medical University, and written informed consent was obtained from all participants. In cases where obtaining consent was impossible, the opt-out model was used based on the guidelines of confidentiality of personal information.

Resin frame method

Computed tomography (CT) was performed for pre- and postoperative evaluations. All CT imaging was performed using a multi-slice helical CT scanner (SOMATOM Sensation16, SOMATOM Sensation40, SOMATOM Sensation64, SOMATOM Definition, SOMATOM Definition AS+, or SOMATOM Definition Flash; Siemens AG, Germany, pr Aquilion CX; Toshiba, Japan), with the patient in the supine position. Preoperative volumetric CT image data were used to make a three-dimensional (3D) model for the resin frame method and for comparison in postoperative evaluations. A ProJet® printer (3D Systems Corporation, Rock Hill, SC) was used to create the 3D model out of gypsum powder, binding agent, and cyanoacrylate as an impregnating agent. An autopolymerizing resin was used for the resin frame. A reconstruction plate with a locking system was used to fix the grafted bone in the resin frame method, whereas a miniplate and screws were used in the conventional method.

Design of the reconstructed mandible

In accordance with the treatment plan, once the range of segmental mandibulectomy and bone graft has been decided (Figure 1), the 3D model is trimmed to design the reconstructed mandible (Figure 2). If fibula is to be used for the grafted bone, the form of the fibula is considered and the model of the reconstructed mandible is trimmed into a shape combining straight lines (Figure 2). The fibula is divided into several fragments, with the reconstructed mandible designed to match the form of the original mandible. If iliac bone or scapula is to be used as the grafted bone, the reconstructed mandible is trimmed to ensure left-right symmetry. Taking circulation into account, the reconstructed mandible is designed so that the grafted bone size is ≥2.5 cm.

Creation of the resin frame

Preoperatively, the position of the reconstruction plate is aligned to the 3D model and pre-bending is performed Figure 3(A–C). At the position where the reconstruction plate is fixed to the 3D model, the position from the lower edge of the reconstruction plate and lower edge of the mandible is marked with autopolymerizing resin, which is then cured to create the resin frame Figure 4(A–C). During bi-cortical fixing, the height of the edge

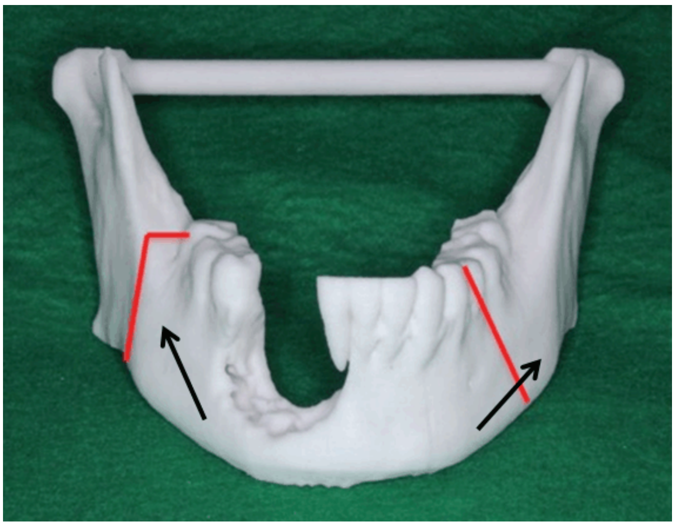

Figure 1: Planning of the segmental mandibulectomy (arrow).

of the frame on the tongue side is set to be less than that of the screw holes and is set in advance to minimize periosteal detachment. In addition to the frame structure used to accurately reposition the residual mandible and reproduce the fixation position of the reconstruction plate, an apparatus is incorporated to provide perioperative stability. The frame inlaid with the reconstruction plate, the frame inlaid with the lower edge of the mandible, and the screw holes for provisionally fixing the resin frame to the residual mandible are shown in Figure 5c, respectively Figure 5(A and B). Because the remaining pieces from the reconstruction plate with locking system and incorporated into the resin frame, the locking system acts to prevent resin frame breakage and mandibular deviations caused by excessive tightening during provisional fixation. The wing prevents the mandible from rotating when the residual mandible is repositioned Figure 5(A and B). Mounting and repositioning of the reconstruction plate in the resin frame uses the reconstruction plate itself as a wing.

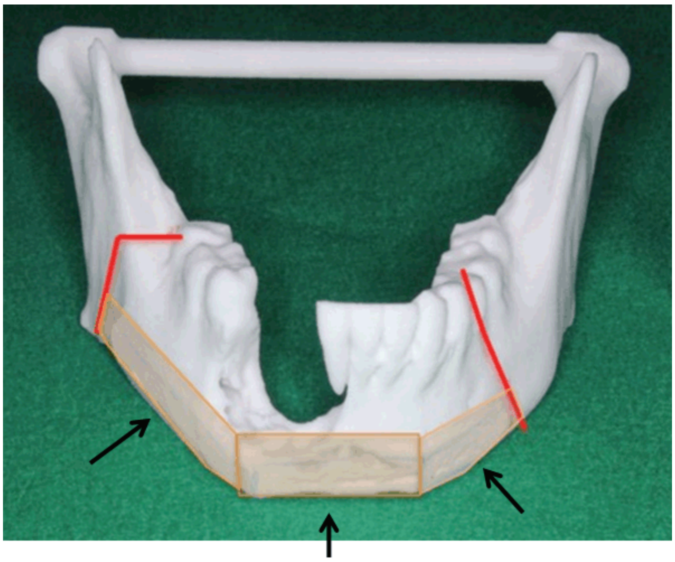

Figure 2: Trimming of the 3D model to fit the form of transplanted bone (arrow).

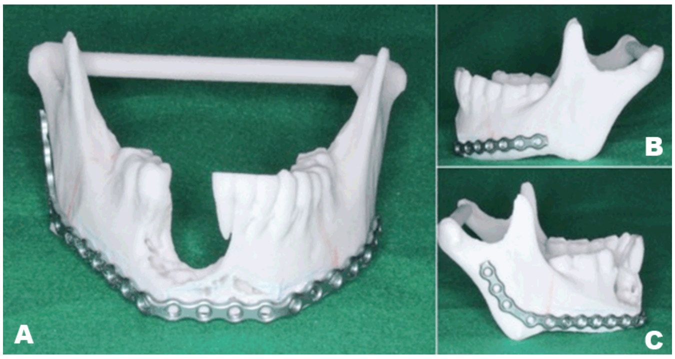

Figure 3(A–C): Pre-bending of the reconstruction plate.

Figure 4(A–C): Production of the resin frame (arrow).

Creation of a position template for mandibulectomy

To perform segmental mandibulectomy at the correct site, a template showing the resection position is created using autopolymerizing resin (Figure 6).

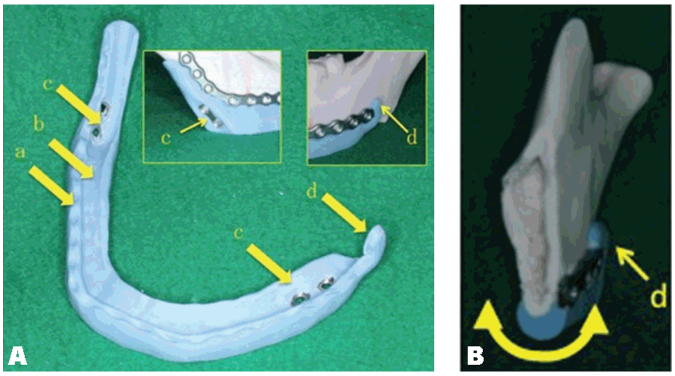

Figure 5(A and B): Structure and characteristics of the resin frame. (a) The frame inlaid with the reconstruction plate. (b) The frame inlaid with the lower edge of the mandible. (c) The screw holes for provisionally fixing the resin frame to the residual mandible. (d) The wing prevents the mandible from rotating when the residual mandible is repositioned.

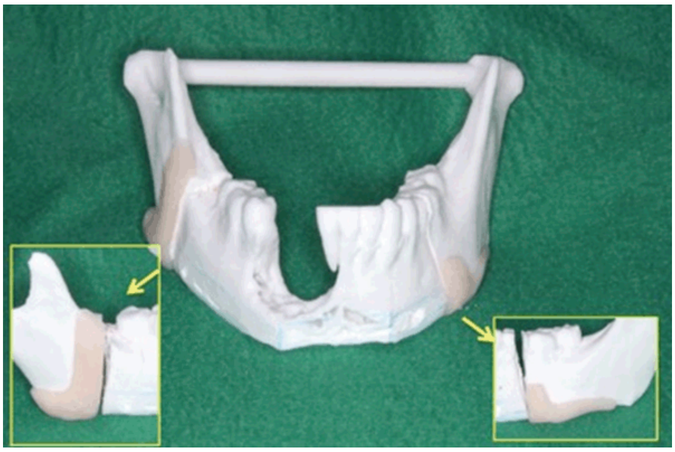

Figure 6: Manufacture of the surgical template for segmental mandibulectomy.

Creation of the grafted bone model

A model of grafted bone placed in the defective parts of the mandible is created using autopolymerizing resin by taking an impression of the 3D model after subjecting the model to the planned mandibulectomy (Figure 7).

Reproduction of separated parts of the mandible

Using the segmental mandibulectomy template created from the 3D model, the separated part of the mandible is accurately reproduced and separated (Figure 8).

Reconstruction of occlusal units and repositioning of preserved mandibular bone within the resin frame

Combining the use of a bite plate and a wire splint or intermaxillary anchorage screws, intermaxillary anchorage is performed and the occlusal unit is reconstructed. Next, with the reconstruction plate mounted in the resin frame, the residual mandible is repositioned and continuity is restored (Figure 9).

Confirming reproducibility of preoperative design

Models of grafted bone are inserted into the defective parts, to check whether the resin frame has been correctly mounted and to ensure the preoperative design has been reproduced (Figure 10).

Reconstructed plate fixation, resin frame removal, and grafted bone placement and fixation

The reconstructed plate is fixed to the residual mandible and the resin frame is removed. Using the reconstructed plate as an indicator, the grafted bone is adjusted and residual bone is placed and fixed (Figure 11) (Figure 12).

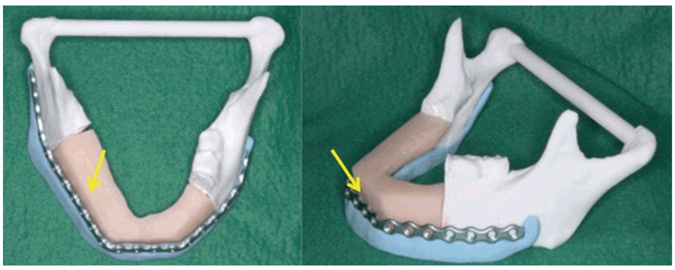

Figure 7: Manufacture of the transplant bone model with planned mandibular reconstruction (arrow).

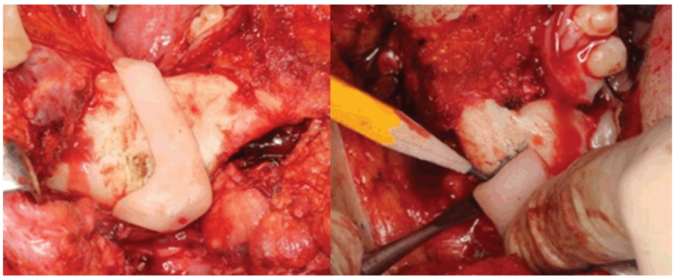

Figure 8: Reproduction of segmental mandibulectomy in the operative field using the surgical template.

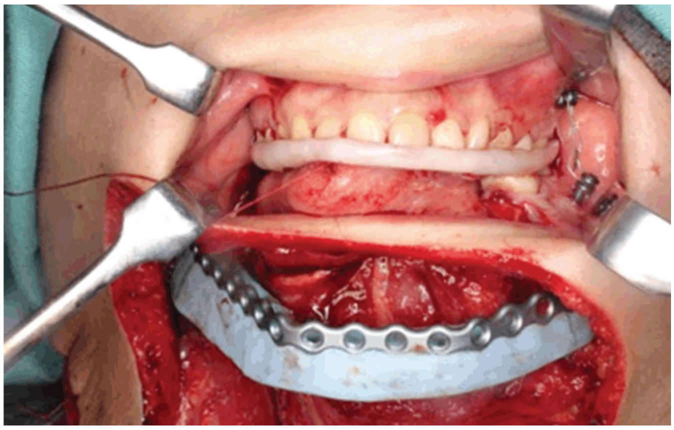

Figure 9: Rebuilding of the occlusal unit.

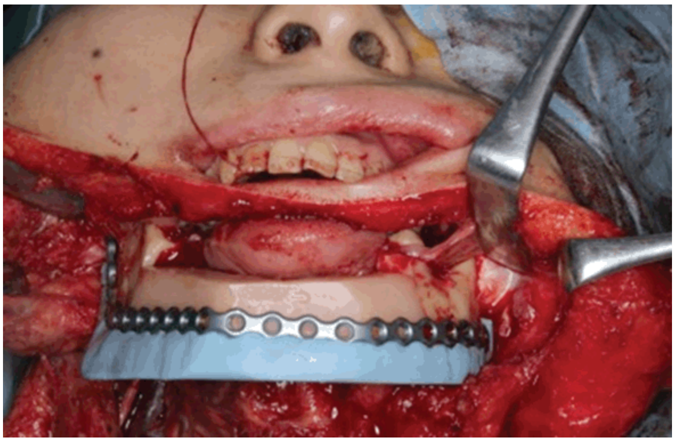

Figure 10: Reproducible confirmation of mandible reconstruction design.

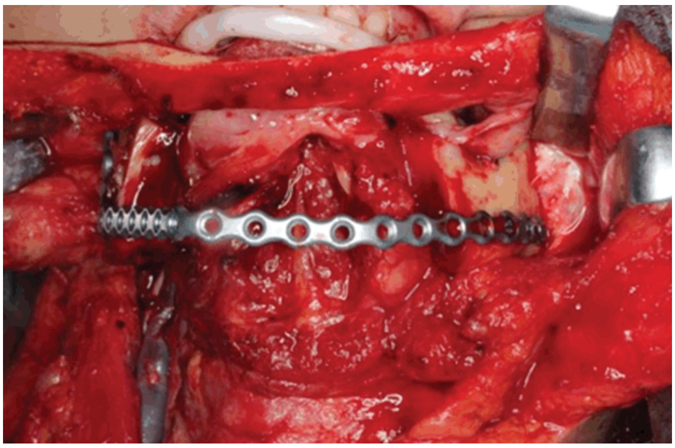

Figure 11: Removal of the resin frame.

Image evaluation method for the reconstructed mandible

Digital Imaging and Communications in Medicine (DICOM)-format CT image data from the patient with the reconstructed mandible were forwarded from the treatment database to the dedicated image-processing terminal used in the study. DICOM data from before and after the operation were saved. OsiriX image analysis software (OsiriX Foundation, Geneva, Switzerland) was used to create volume-rendered 3D images showing transverse cross-sections of the lower edge of the mandible at the corresponding height of each of the graft bones and the contours of the mandible (Figure 12). Mandibular defects were categorized into the various regions of the mandible (mental region (M), mandibular body region (B), and ramus of the mandible (R)), and regions that included defects were combined. Using the residual mandibular condyle, mandibular angle, and mental spine as references, the lower edge of the mandible after the operation was set to match the lower edge of the mandible before the operation. Pre- and postoperative 3D images were converted to JPEG files, and Adobe Photoshop Elements version 13 editing software (Adobe Systems, San Jose, CA) was used before and after the operation to trim the parts of the image that did not include the mandible. The layer function was then used to fuse pre- and postoperative 3D images Figure 13(A–C). The area of the mandibular body in pre- and postoperative images and total area of the mandibular body in the fused image were measured in pixels. Based on measured area, the concordance rate as the percentage match between total area and common area was calculated. We evaluated differences in concordance rates between the resin frame method and conventional method of mandibular reconstruction Figure 13(A–C). A Mann-Whitney U test confirmed these results. The significance level of all of tests was $\alpha = 0.05$. SPSS version 17J software (SPSS Japan, Tokyo, Japan) was used for all statistical analyses. Probability values of $p<0.05$ were considered to be significant.

Figure 12: Postoperative computed tomography of the mandible. The preoperative design for mandibular reconstruction has been replicated exactly.

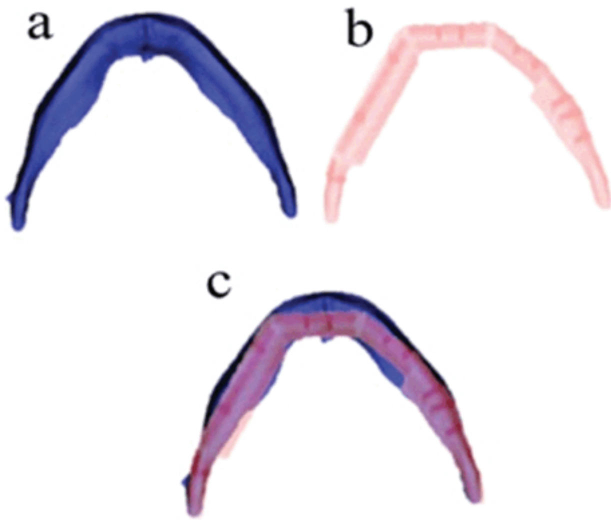

Figure 13(A–C): The layer function is used to fuse pre- and postoperative 3D images. (A) Preoperative image. (B) Postoperative image. (C) Fusion image.

RESULTS

Little difference was seen between the resin frame method group and conventional method group in terms of age, sex ratio, diagnosis, or mandibular defect range (Table 1).

Fibula was frequently used as graft bone in many cases treated using the resin frame method, and many cases used ilium as graft bone in conventional surgery. Regarding the method of graft bone fixation, a reconstruction plate was used in all 25 resin frame cases. In conventional surgery, fixation was achieved using a mini-plate (12 cases), mini-plate and screws (7 cases), or screws alone (6 cases) (Table 2). Concordance rates for the resin frame method and conventional surgery were 75.09±6.09% and 67.39±13.44%, respectively, showing a significant difference ($p=0.032$, $p<0.05$ (Table 3).

Table 1: Patient characteristics

	Mean age (range), years	Sex (n)	Diagnosis (n)
Resin frame method	68.32 (18-91)	Males 14 Females 11	Malignant tumor 20 Benign tumor 3 Others 2
Conventional surgery	64.92 (19-88)	Males 13 Females 12	Malignant tumor 22 Benign tumor 1 Others 2

Table 2: Site of mandibular segmental defect, graft bone, and bone graft fixation for resin frame method and conventional surgery

	Segmental mandibular defects	Graft bone	Bone grafting fixation
Resin frame method	R+B+M+B = 2 R+B = 8 R+B+M = 2 B+M = 4 B+M+B = 5 B = 4	Fibula = 18 Ilium= 7	Reconstruction plate = 25
Conventional surgery	R+B+M+B = 1 R+B = 10 R+B+M = 3 B+M = 4 B+M+B = 3 B = 4	Fibula = 9 Ilium = 16	Mini plate = 12 Screw = 6 Mini plate + screw = 7

R: ramus of the mandible, B: mandibular body region, M: mental region

Table 3: Concordance rates for the resin frame method and conventional surgery

	Resin frame method	Conventional surgery	pa
Concordance rate	75.09±6.09%	67.39±13.44%	0.032

aMann-Whitney U test.
*p<0.05

DISCUSSION

Mandibular reconstructions using vascularized osteocutaneous flaps have been reported since 1977, with reconstructions using fibula, ilium, and scapula as the most common [1, 8, 10–13].

When 3D printing became available, 3D models started to be used for preoperative simulation [14–16]. The following method was developed: on the 3D model, after mandibular separation, a recording repositioning plate was adjusted by bridging to a metal plate between segments of conserved mandible [16–18]. Position of the residual mandible was recorded by mounting the device in the visual field prior to segmental mandibulectomy. Later, a method was reported in which the mandible was repositioned after segmental mandibulectomy on the basis of positional information recorded in the resin before the operation [13]. However, these methods emphasized repositioning of the residual mandible, and the main purpose was to recover subjective masticatory ability [19]. There were few reports about evaluation of the differences in accuracy between mandible reconstruction by free hand versus surgical guide template [20].

In October 2013, we developed the resin frame method using the new concept of "reconstructing mandibular shape and occlusion according to a preoperative design using objective procedures". The resin frame is a device that records the results of mandibular reconstruction performed on a 3D model before the operation by fixing the pre-bent reconstruction plate, using autopolymerizing resin. Using this device, the separated residual mandible is incorporated into the resin frame, allowing easy restoration of continuity [8], while the accurately repositioned and fixed reconstructed plate is used as a guide for positioning the graft bone, enabling objective, highly reproducible, and accurate reconstruction. This finding proved that the concordance rate was significantly higher for the resin frame method than for the conventional method, because the subjectively determined operations by the surgeon using the conventional method were changed to objective operations, eliminating the effects of surgical technique.

The resin frame method offers the following characteristics. First, the 3D model was trimmed and the reconstruction plate was pre-bent to align with the form of the bone that was grafted to the mandible. This "trimming" increased the reproducibility of grafted bone positioning during the operation and minimized gaps between the grafted bone and reconstructed plate. In the conventional method, no "trimming" was performed. Such "trimming" is also believed to greatly affect the postoperative form of the mandible. In addition, the template was created for segmental mandibulectomy, according to the preoperative plan, improving the accuracy of reproduction for the separated parts of the mandible. These operations eliminated the adverse effects of fixation of a reconstruction plate and transplanted bone on the design and fixation of the grafted bone.

Second, the reconstructed mandible designed preoperatively showed high reproducibility. By positioning and fastening the reconstructed plate according to the preoperative design, the plate could readily be used as a target to place and fix grafted bone. Also, inserting the grafted bone model into separated parts of the mandible to increase reproduction accuracy made it possible to ensure that the mandible was accurately separated and the residual mandible and plate were positioned according to the preoperative design. In addition, the "wing" projection was added to prevent fastening to grafted bone when the reconstruction plate was distorted and to prevent resin frame rotation or distortion, which increased reproducibility when the resin frame was mounted. The absence of any cases of dislocation or forward rotation of the articular process, which occurred after operations using the conventional method, and the significantly higher concordance rate with the resin frame method verified the efficacy of the wing.

Third, occlusion was restored. When continuity of the mandible is broken via segmental mandibulectomy and a splint alone is used to fasten the bone, rotation occurs as a result of over-tightening of the intermaxillary fixing wire, causing postoperative occlusion that differs from preoperative occlusion. With the resin frame method, if the jaw is not edentulous, a bite plate can be created before the procedure and used in combination with intermaxillary fixing screws perioperatively to reproduce occlusion.

In medical fields, 3D imaging and printing applications have received much attention [4, 15, 21], but most presuppose the use of a large-scale operation simulation/navigation system or CAD/CAM system [5–7, 22]. In recent years, simulations have been used to create many systems for recipient and donor sites, and even to pre-bend fixation devices [5–7, 22]. However, those applications are not generally used because they involve many operation steps, causing most of the time to be spent on capital investment and learning the systems. In contrast, the resin frame method has the advantage of easy introduction to current facilities without the need for new equipment. This is because inexpensive gypsum 3D models can be created by outsourcing and then modified by the surgeons themselves, for use in assisting with surgical procedures.

Currently, while highly accurate resection of the graft bone can be performed using surgical guides, reconstruction plate bending or fixation maneuvers are still greatly influenced by the skills of the surgeon [23].

In the resin frame method, preoperative design of the donor site does not have to be excessively strict. This is because the model provides flexibility for adjusting anastomotic vessels and bone graft fragments as well as perioperative occlusal reconstruction. Fixation of the grafted bone is objective and does not affect the form of the reconstructed mandible, since a reconstruction plate fixed according to the preoperative design is placed as a guide. In addition, the accuracy of a 3D model of the jaw is affected by various elements, from CT imaging devices and data-editing software to molding devices, so errors can also occur in virtual simulation. Conserved occlusion is restored by reconstruction of the occlusal unit first (similar to occlusal restoration in mandibular fractures), followed by restoration of the detached mandibular bone to restore the mandibular morphology.

CONCLUSION

The resin frame method is a hybrid of the conventional method and a virtual simulation system. By systematizing mandibular reconstruction procedures and increasing objectivity, this method successfully improves mandibular reconstruction accuracy from an aesthetic and functional standpoint.

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Author Contributions
Junichi Hayasaka – Substantial contributions to conception and design, Acquisition of data, Analysis and interpretation of data, Drafting the article, Revising it critically for important intellectual content, Final approval of the version to be published
Shunji Sarukawa – Analysis and interpretation of data, Revising it critically for important intellectual content, Final approval of the version to be published
Hiroto Itoh – Analysis and interpretation of data, Revising it critically for important intellectual content, Final approval of the version to be published
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Guarantor of Submission
The corresponding author is the guarantor of submission.

Source of Support
None

Consent Statement
Written informed consent was obtained from the patient for publication of this study.

Conflict of Interest
Authors declare no conflict of interest.

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