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Original Article

Use of reconstruction plates prebent on three-dimensional models to reduce the complications of mandibular reconstruction

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Segmental mandibulectomy;
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Abstract *Background/purpose:* Though the gold standard method for mandible reconstruction of the defect from segmental mandibulectomy is by osseous flap or graft, using reconstruction plates is still indicated in some cases. Traditionally, the plate is bended immediately after the segmental mandibulectomy by freehand. However, it's difficult to fit well to the original position of mandible, which may result in more complications. This study therefore aimed to investigate whether using prebent plates on computer-aided 3D printing models could reduce the complication rate.
Materials and methods: Patients who received mandible reconstruction by reconstruction plate from 2018 to 2022 were enrolled and evaluated in this study. The data, including demographics, indications for surgery, pre-existed preoperative and postoperative therapies, classification of defects, and postoperative outcomes were collected and analyzed.
Results: A total of 52 patients were enrolled in our study. The prebent group exhibited a significantly lower complication rate than that of the immediately bent group ($P = 0.012$). Other risk factors of plate complications included postoperative adjuvant radiotherapy ($P = 0.017$) and previous surgery ($P = 0.047$). The complication-free survival rate was also better in the prebent group in a 3-year follow-up period ($P = 0.012$).

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Conclusion: Prebent plates on computer-aided printing models proved to be an effective approach to reduce the complications for mandibular reconstruction in segmental mandibulectomy.

Introduction

The goals of mandibular reconstruction are to reestablish the shape of the lower third of the face and restore the functions of the oral cavity and upper airway, such as eating, speaking, and breathing.[1] Options for the reconstruction of segmental defects after segmental mandibulectomy include osseous free flaps, reconstruction with metal plates covered by soft tissue, bone grafts, and simple soft tissue coverage with a discontinuous mandible. The selected method is dependent on the defect size and site, associated soft tissue defects, the systemic condition of the patient, and the disease prognosis.[2] For patients with advanced malignant diseases, adjuvant radiotherapy must begin within 6 weeks after the operation to maximize survival.[3] Thus, a complication-free reconstruction plan for such patients should be devised.

Reconstruction using free osseous flaps after segmental mandibulectomy is the gold standard; however, for patients with poor prognosis, no suitable osseous flap and persistent comorbidities, simpler reconstruction plans are preferable. For such patients, the use of bridging plates combined with a soft tissue free flap is an effective method when postoperative radiotherapy must begin as early as possible.[4] After segmental mandibulectomy, bending the bridging plate precisely through freehand techniques is difficult. If the bridging plate is in an incorrect position, plate fracture, plate exposure, and screw loosening may occur.[5] Prebent plates before segmental mandibulectomy offer several advantages, such as requiring a shorter surgical time, being easily adapted, reducing metal fatigue, and improving the detection of recurrent disease.[6] This study investigated the outcomes of using prebent reconstruction plates on the 3D-printed computer-aided design (CAD) models.

Materials and methods

Study population

We retrospective reviewed the patient using reconstruction plate for mandible reconstruction between 2018 and 2022. The follow-up period ranged from 6 months to 4 years 11 months. The inclusion criterion was patient who received segmental mandibulectomy. Reconstruction plates of Stryker universal 2.7 mm mandibular plates (Styker, Kalamazoo, MI, US) or DePuy MatrixMANDIBLE™ preformed reconstruction *plates* (Johnson & Johnson, Bristol, MA, US) were used to replace the bone defects, which were covered by a soft tissue flap, either a free soft tissue or local flap.

The clinical data collected included the patients' general information, body mass index, indications for surgery, history of radiotherapy and surgery, classification of the bone defect, postoperative chemotherapy and radiotherapy, causes of plate failure, and survival status.

Defect classification

The defects were classified according to the hemimandible condyle lateral (HCL) classification. Type-C (central) defects are those across the symphysis region, including both canines. Type-L (lateral) defects are lateral and have no condylar involvement. Finally, type-H (hemimandible) defects are lateral defects with condyle involvement. Defects with multiple types are represented with a combination of the corresponding letter (e.g., type-LC).[7]

Plate prebent technique

In prebent group, indicating that it received bending reconstruction plates before mandibular segmentation on 3D-printed models or directly on the outer surface of the mandible during surgery before mandible segmentation. The 3D model was manufactured according to the high resolution mandible computed tomography data (slice thickness less than 1 mm) to segment specific soft/hard tissue and the model was fabricated by photosensitive resin made of liquid photopolymers (Ever Young BioDimension, Taichung, Taiwan). The bulging region of mandible was removed before model printing by virtual surgical planning software (Geomatics Design X, Artec Senningerberg, Luxembourg) or ground by hand after the 3D models were formed (Fig. 1A arrow). When the plate was bent directly on the bone surface, the interfering mandibular surface was ground without influence from the surgical area or margins before plate bending. After segmentation of mandible, the plate was fixed on the mandible according to the reference position on model (Fig. 1B). If free flaps were used for reconstruction, the flaps with de-epitheliation on their cutaneous surface or the muscles from the chimeric flaps would be inserted on outer surfaces of the plate (Fig. 1C). The spaces between the plate and lingual tissue on the lingual side were also filled in with muscle tissue. Thus, the metal plates were wrapped in soft tissues to reduce possible complications due to high direct pressure on the plates.

Statistical analysis

The distribution of patients' demographic characteristics was analyzed by using mean and standard deviation (SD) for age. One-way analysis of variance (ANOVA), chi-square test or Fisher's exact test was further used for group comparisons range. The plate complication survival was analyzed by Kaplan-Meier analysis. All statistical analyses were

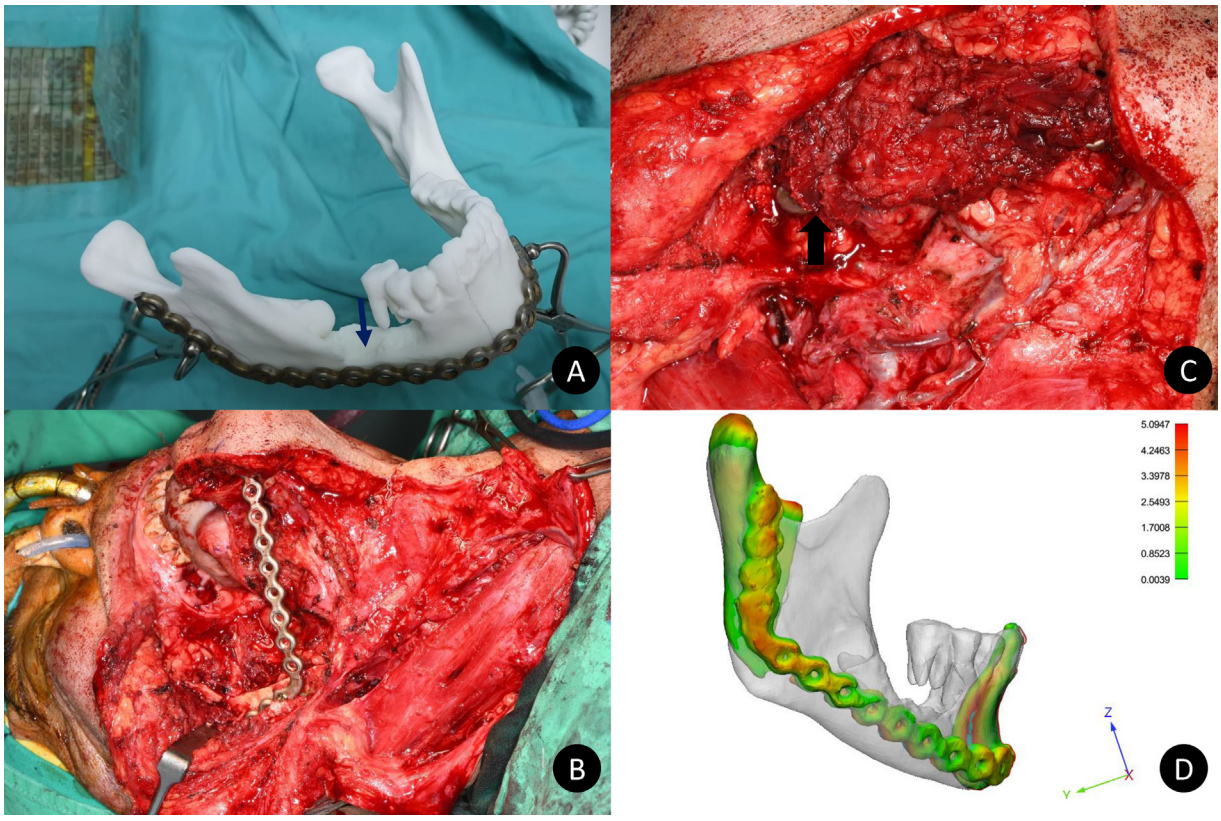


Figure 1 Patient with gingival cancer who received segmental mandibulectomy. (A) CAD model for prebending mandibular reconstruction plate. The convex region of the mandible was shrunk and recontoured in the model (thin arrow). (B) The prebent reconstruction plate was inserted in the mandibular defect after tumor ablation and mandibulectomy. (C) Muscle from the vastus lateralis and de-epithelialized skin from the anterolateral thigh (thick arrow) were used to wrap the plate. (D) Geometric morphometric analysis revealed some postoperative positioning error near the condylar head.

performed using SAS version 9.4 (SAS Institute, Cary, NC, US). $P < 0.05$ was considered statistically significant.

Results

A total of 52 patients (1 woman and 51 men) were enrolled in this study. The collected cases comprised 47 (90.3%) cases of oral squamous cell carcinoma, 2 (3.8%) cases of osteoradionecrosis, 1 (1.9%) case of osteomyelitis, and 2 (3.8%) cases of medication-related osteonecrosis of the jaw (MRONJ). Among these patients, 36 (69.2%) had type-L defects, 8 (15.3%) had type-CL defects, 5 (9.6%) had type-LCL defects, and 3 (5.7%) had type-C defects. The prebent technique was used in 36 patients. Among them, 33 cases used 3D printing models and 3 cases fit directly on the outer contour of mandible before segmentation. Seventeen patients (32.6%) had previously received radiotherapy, and 19 patients (36.5%) received previous surgeries in plating region. Forty-one patients (69.2%) received postoperative treatment, including radiotherapy only or chemotherapy or concurrent chemo-radiotherapy (Table 1).

Postoperative complications occurred in 13 of 52 patients (25%) and we analyzed several parameters of complication. The result showed 5 cases in the prebent group (38.5%) and 8 cases (50%) in the non-prebent group. The complication rates were significantly different between these two groups ($P = 0.012$). Among the 13 patients with postoperative complications, 11 experienced plate exposure, 1 experienced screw loosening, and 1 experienced plate fracture. After these complications were noticed, the reconstruction plates were removed from six patients without further reconstruction, and four patients required plate reconstruction with fibula osteocutaneous free flaps. For the remaining three patients, the follow-up period was insufficient to determine the appropriate course of action. For other risk factors, 8 of 17 (47%) patients with a history of radiotherapy experienced complications ($P = 0.012$), and 8 of 19 (42.1%) with a history of surgery experienced complications ($P = 0.047$; Table 2).

Through univariate analysis, we determined the hazard ratios (HRs) for non-prebent plates (HR = 3.91, 95% CI: [1.24–12.38], $P = 0.020$), postoperative adjuvant radiotherapy (HR = 2.83, 95% CI: 1.12–7.16, $P = 0.027$), a history of radiotherapy (HR = 3.47, 95% CI: 1.12–7.16, $P = 0.036$), a history of surgery (HR = 4.74, 95% CI: 1.4–16.03, $P = 0.012$), and bone cutting region including C (type C, LC, or LCL) (HR = 3.29, 95% CI: 1.05–10.3, $P = 0.04$), which as all appeared to be significant risk factors for postoperative complications. We further analyzed these factors through multivariable regression adjusted for all clinical factors. The HR for only non-prebent plates remained significant (HR = 5.77, 95% CI: 1.47–22.65, $P = 0.012$). The HR for type-C bone defects

Table 1 Clinical characteristics of the enrolled patients.

Clinical characteristics	No of patients (%)
Sex	
Male	51 (98.1%)
Female	1 (1.9%)
Cause of mandibulectomy	
Oral squamous cell carcinoma	47 (90.3%)
Osteoradionecrosis	2 (3.8%)
Osteomyelitis	1 (1.9%)
Medication-related osteonecrosis of the jaw	2 (3.8%)
Defect classification	
Type-L	36 (69.2%)
Type-CL	8 (15.3%)
Type-LCL	5 (9.6%)
Type-C	3 (5.7%)
Plate management	
Prebent	36 (69.2%)
Bending with free hand	16 (31.8%)
Pre-operative management	
Non	31 (59.6%)
Radiotherapy	2 (3.8%)
Surgery	4 (7.6%)
Radiotherapy and surgery	15 (28.8%)
Post- operative management	
Non	11 (21.1%)
Radiotherapy or chemotherapy	41 (78.8%)
Status of plate	
Present	39 (75%)
Plate expose	11 (21.1%)
Screws loosening	1 (1.9%)
Plate fracture	1 (1.9%)

Abbreviations: Type C (Central) defect means the mandibulectomy encompassing the region across the symphysis area and possibly containing canines. Type L (Lateral) defect locates laterally without condyle involvement. Other combinational variants include type CL representing central-lateral defect and type LCL depicting lateral-central-lateral defect.

Table 2 Demographic characteristics of the enrolled study participants.

	Plate complication (N = 13)	plate no complication (N = 39)	*P* value
Age, Mean (SD), years	62.7 (7.4)	59.5 (9.5)	0.282*
BMI Mean (SD)	22.6 (3.3)	23.1 (3.2)	0.648*
Prebent n (%)	5 (38.5)	31 (79.5)	0.0128**
Post op RT n (%)	9 (69.2)	27 (69.2)	1**
Post chemo n (%)	10 (76.9)	31 (79.5)	1**
Previous RT n (%)	8 (61.5)	9 (23.1)	0.017**
Previous surgery n (%)	8 (61.5)	11 (28.2)	0.047**
Cutting C n (%)	6 (46.2)	10 (25.6)	0.184**

Abbreviations: RT, radiotherapy; chemo, Chemotherapy; Type C (Central) defect means the mandibulectomy encompassing the region across the symphysis area and possibly containing canines. Type L (Lateral) defect locates laterally without condyle involvement. The "Cutting C" indicates all the defect types involving central area, which includes type C (central), type LC (lateral-central), and type LCL (lateral-central-lateral).
*Categorical variable: Chi-square test; ***P* values were calculated using Fisher's exact test.

was high but no significant (HR = 4.13, $P = 0.06$), possibly because of the low number of patients in our study. Other risk factors exhibited high HRs in the multivariable analysis, but none of them reaching significance (Table 3).

The earliest onset of plate complications was 3 months after surgery in the prebent group and 2 months in the non-prebent group. The primary complication was plate exposure. A Kaplan—Meier curve indicated that the 1-, 2-, and 3-year complication-free rates were 84.8%, 84.8%, 84.8%, respectively, in the prebent group and 58.9%, 49.1%, 49.1% in the non-prebent group. The complication-free rates in the groups were significantly different ($P < 0.012$; Fig. 2).

Discussion

Model-based prebent plate for mandibular reconstruction has been advocated for many years.[8] Compared with plates conventionally bent freehand after resection, use of prebent plates can result in more desirable postoperative mandibular contour and positioning and shorter operative time compared.[6,9]

The most common complication of plate reconstruction is plate exposure. The incidence of plate exposure ranges from 3.7% to 75%.[10] The factors for plate exposure include postoperative radiotherapy, intraoperative blood loss, dead space around the plate, thin soft tissue coverage, the extent of mandibular resection, unbalanced distribution of the soft tissues on the plate surface, and plate bulging.[4,5] Preventive measures include filling the dead space around the plates, placing soft tissue with sufficient thickness over the surface of the plate, and shaping and adjusting the plate adequately before surgery using 3D models.[5]

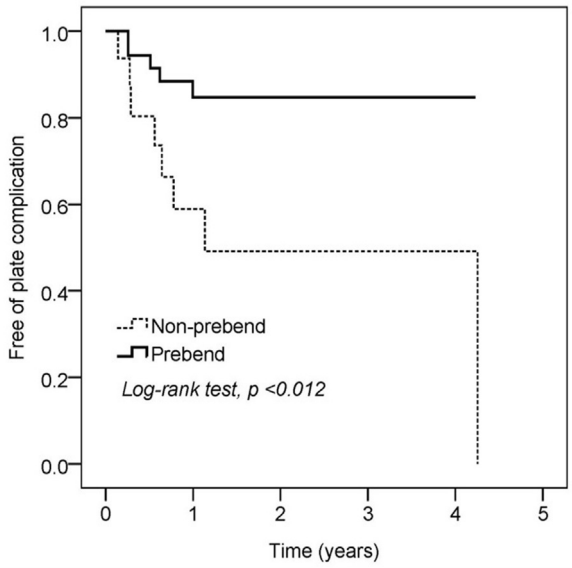
Plate fracture is another common complication and usually results from additional stress induced by bending for adjustment during the operation; such stress affects the distribution of stress under fatigue.[11] The incidence of plate fracture ranges from 4% to 11%, and the risk factors include a long defect length and type-LC bone defects.[10] Methods for reducing the incidence may include using 3D-printed reconstruction plates or strengthening the plate.[10,12,13]

The complication rate in the prebent group in our study was 13.8% during follow up, which is lower than those observed in other studies.[4,10] Our more favorable outcomes may be due to not only our use of prebent plates for reconstruction but also our minimization of over-contouring through the use of 3D-printed models. Moreover, during surgery, we applied de-epithelialized free cutaneous flaps or muscles from chimeric free flaps to cover as much of the lateral surfaces of the plates as possible. The space between the plate and lingual tissue was also filled with muscle from the chimeric flaps. Many studies advocate several methods to lower the complication of using plate.[5,6,8,10,12,13] To our knowledge, this is the first study that analyzed the complication rates of mandibular

Table 3 Cox proportional hazards model for risk of plate complications.

	Univariate		Multivariate	
	HR (95% C.I.)	*P* value	HR (95% C.I.)	*P* value
Non-Prebent	3.91 (1.24—12.38)	0.020	5.77 (1.47—22.65)	**0.012**
Post op RT	1.44 (0.39—5.32)	0.586	1.55 (0.11—21.01)	0.743
Post op chemo	1.59 (0.35—7.29)	0.547	0.69 (0.05—10.73)	0.793
Previous RT	3.47 (1.09—11.09)	**0.036**	0.76 (0.08—6.96)	0.805
Previous surgery	4.74 (1.40—16.03)	**0.012**	7.65 (0.66—88.18)	0.103
Cutting C	3.29 (1.05—10.30)	**0.040**	4.13 (0.94—18.08)	0.060

Abbreviations: RT, radiotherapy; chemo, Chemotherapy; Type C (Central) defect means the mandibulectomy encompassing the region across the symphysis area and possibly containing canines. Type L (Lateral) defect locates laterally without condyle involvement. The "Cutting C" indicates all the defect types involving central area, which includes type C (central), type LC (lateral-central), and type LCL (lateral-central-lateral), The numbers shown in bold were those with significance in statistical analysis.



	Rate		
Free of plate complication	1-year	2-year	3-year
Prebent	0.848	0.848	0.848
Non-prebent	0.589	0.491	0.491

Figure 2 Kaplan—Meier curve illustrating the complication-free survival rate after reconstruction with prebent plates.

reconstruction with prebent reconstruction plates enhanced through soft tissue management. In Taiwan, 3D-printed reconstruction plates have not yet been approved by the Food and Drug Administration. Furthermore, 3D printing metal plates is time consuming and expensive, and many patients with oral cancer, especially those who require urgent treatment, lack private medical insurance.

Whether preoperative or postoperative radiotherapy, as well as the type or position of the defect, affects the risk factors for plate complications is still debatable. Nicholson et al. revealed that neither preoperative nor postoperative radiotherapy was associated with an increase in plate exposure.[14] Paolo et al. found that postoperative but not preoperative radiotherapy to be a risk factor.[4] Mariani et al. identified factors that exacerbate complications, which included postoperative radiotherapy and defects being located in the central region of mandible.[15] Masaya et al. observed a significant increase in plate failure in patients with anterolateral defects (type-CL and type-LCL) and those who received preoperative radiotherapy.[16] In our study, a history of radiotherapy and plates located in previous surgical regions were the prominent risk factors. These results may be caused by tissue shrinkage and fibrosis due to prior treatment, which resulted in poor tissue perfusion and healing around the plates. Mandibulectomy across the central region of mandible was another major risk factor. The contour and structure of the chin region create a complex, convex shape, and this shape affects the movement and force distribution of the jaw. Certain shapes may create pressure on the thin skin covering the reconstruction, which can result in plate exposure. Using CAD and computer-aided manufacturing (CAM) mandibular models offers the benefit of allowing surgeons to accurately shape the plates before surgery, thereby eliminating over-contouring and convexity and ensuring the optimal fit. Such models can be used to greatly reduce the effects of postoperative tissue tension on flaps and the metal fatigue from bending procedures repeated before or during surgeries.

In our study, most complications occurred during the first year after surgery but stabilized during the second or third year; this observation is consistent with those of other studies.[4,16] However, the complication-free survival rate observed in our study was higher than those observed in other studies. Nonetheless, our study has several limitations. First, the follow-up period was short. Due to several late-stage cases, the patient may suffer from tumor recurrence, expire in short time. Second, because the gold standard is to use free osseous flaps for mandibular reconstruction, the number of patients in our study was limited. Third, position error between model and mandible may still have occurred because the plate is still bended by hand. (Fig. 1D).

In conclusion, prebent plates on computer-aided printing models are proved to be an effective approach to reduce the complications for mandibular reconstruction in segmental mandibulectomy.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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