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Oromandibular reconstruction using microvascularized bone flap: report of 1038 cases from a single institution

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Abstract. This retrospective study was performed to review 1038 patients who underwent mandibular reconstruction with free vascularized bone flaps at a single institution between 2006 and 2017. Of these patients, 827 (79.67%) had fibula flaps, 197 (18.98%) had deep circumflex iliac artery perforator (DCIA) flaps, and 11 (1.06%) had scapula bone flaps. The most common pathological diagnosis was ameloblastoma (n = 366, 35.26%), followed by squamous cell carcinoma (n = 278, 26.78%) and osteoradionecrosis (n = 152, 14.64%). Fifty-seven patients (5.49%) had major complications requiring surgical intervention and one patient died of a pulmonary embolism. Venous crisis was the most frequent major complication (n = 20, 1.93%), followed by haematoma (n = 17, 1.64%) and flap necrosis (n = 14, 1.35%). One-stage mandibular reconstruction was preferred whenever possible, as this generally decreases the financial and hospitalization burden. The four-segment method of jaw reconstruction appeared to achieve good aesthetic appearance results in Asian patients and this was not associated with a higher risk of segment ischemia compared with the three-segment method.

Key words: mandibular reconstruction; free vascularized bone flap; complications.

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Mandibular defects due to tumour ablation, infection, or traumatic loss can impair the patient's appearance, as well as speech, swallowing, mastication, and other functions. However, the treatment of these defects remains a challenge for oral and maxillofacial surgeons. Since the advent of microsurgery in the 1960s, free vascularized bone flaps have been considered the treatment of choice for the restoration of mandibular defects. Taylor was the first to use the vascularized fibula flap to repair a compound defect of the leg[1]. In 1989, Hidalgo reported mandible reconstruction with the use of a fibula flap[2]. Since then, vascularized and non-vascularized bone flap transfer has become a standard method for the repair of mandibular defects.

The accumulation of experience and improvements in surgical technique have

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further increased the potential to reconstruct the mandible, and now many cases once thought to be inoperable are being treated with vascularized or non-vascularized bone flap transfer with a high success rate and minimal complications. At Shanghai Ninth People's Hospital Affiliated to Shanghai Jiao Tong University School of Medicine, most patients gain a better appearance and masticatory function after dental implantation. If possible, the segmental mandibulectomy and reconstruction are performed simultaneously, making it possible to save time and money. The aim of this study was to review the authors' experience of mandibular reconstruction in order to improve the success rate in the future.

Materials and methods

The cases of 1038 patients who had undergone mandibular reconstruction at a single institution during the period January 2006 to December 2017 were reviewed retrospectively (Surgical Oncology Ward of the Department of Oral and Maxillofacial Surgery from 2006 to 2012, later renamed the Department of Oral and Maxillofacial–Head and Neck Oncology from 2012 to 2017, at Shanghai Ninth People's Hospital Affiliated to Shanghai Jiao Tong University School of Medicine). Patients with complete medical records, including demographic, clinical, surgery, and radiography data, were included. The following data were collected: diagnosis, history of radiotherapy, flap type, vessels at the recipient site, location of the defect, management of the jaw, segments and length of the bone flap, dental implantation, and complications. Complications were divided into major and minor ones. Major complications included those that were life-threatening or required a surgical intervention, while minor complications included those that could be treated conservatively. Failure of reconstruction was indicated by flap necrosis and the need for postoperative removal. Data were collected in a table format in Microsoft Excel 2015 (Microsoft Corporation, Redmond, WA, USA).

Table 1. Flap types.

Flap type	2006–2012		2013–2017		2006–2017	
	Cases, *n*	Proportion	Cases, *n*	Proportion	Cases, *n*	Proportion
Fibula bone flap	330	75.00%	497	83.11%	827	79.67%
DCIA flap	104	23.64%	93	15.55%	197	18.98%
Scapula bone flap	6	1.36%	5	0.84%	11	1.06%
Rib flap	0	0	3	0.50%	3	0.29%
Total	440	100%	598	100%	1038	100%

DCIA, deep circumflex iliac artery.

Results

The 1038 patients included in this study ranged in age from 7 to 78 years, with a mean age of 42.71 years. Regarding the sex distribution, 606 (58.38%) were male and 432 (41.62%) were female. The types of flaps used are listed in Table 1. The fibula myocutaneous flap was the most commonly used flap (827/1038, 79.67%), which was applied to almost all types of defect; this was followed by the deep circumflex iliac artery perforator (DCIA) flap (197/1038, 18.98%), which was not applied to extensive mandibular defects, and then the scapula bone flap (11/1038, 1.06%) and rib flap (3/1038, 0.29%) (Figs. 1–3).

The most common pathological diagnosis was ameloblastoma (366/1038, 35.26%), followed by squamous cell carcinoma (278/1038, 26.78%) and osteoradionecrosis (152/1038, 14.64%). However, there were also other benign and malignant tumours and inflammatory lesions (Table 2).

The first choice of recipient artery was the facial artery (596/1038, 57.42%), followed by the superior thyroid artery (267/1038, 25.72%), transverse cervical artery, lingual artery, and external carotid artery. With regard to the recipient vein, the external jugular vein (EJV) (447/1038, 43.06%) and the common facial vein (263/1038, 25.34%) were the most commonly used. However, the venae comitantes and other unnamed branches of veins were also used as recipient veins, especially in patients who had undergone radiotherapy and for other minor indications (Tables 3 and 4).

Of the 1038 patients, 926 were discharged uneventfully and 112 had various complications. Local infection was the most common minor complication, and most of these infections could be treated with antibiotics or drainage. However, debridement under general anaesthesia was required in some patients. Fifty-seven

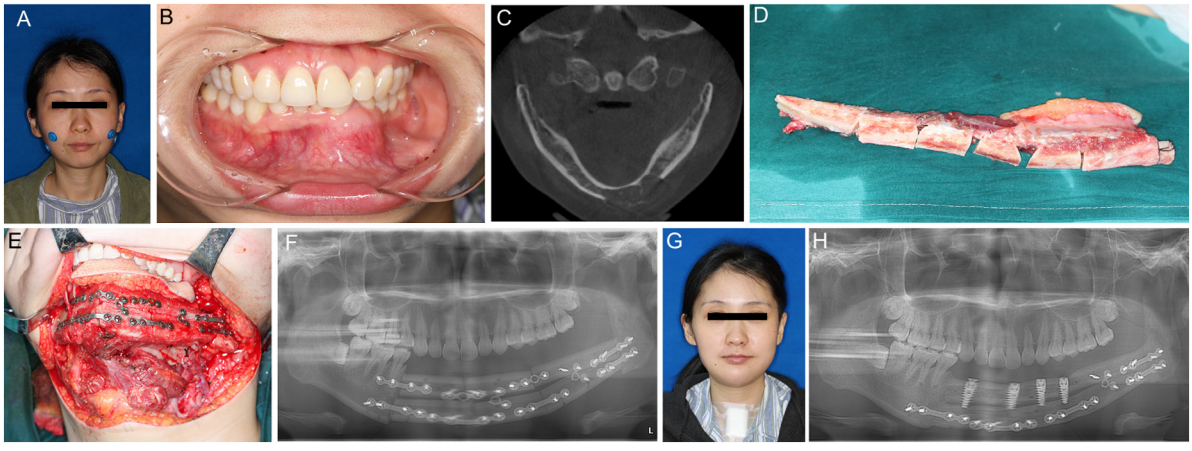

Fig. 1. A 30-year-old female patient with ameloblastoma of the mandible. (A) Facial photograph before surgery; (B) oral photograph and (C) computed tomography image of ameloblastoma of the mandible; (D) fibula myocutaneous flap harvest and osteotomy; (E) double-barrel mandibular reconstruction with the fibula flap; (F) panoramic radiograph and (G) facial photograph showing an excellent postoperative appearance and sufficient height of the mandible; (H) panoramic radiograph showing dental implantation at 1 year post-surgery.

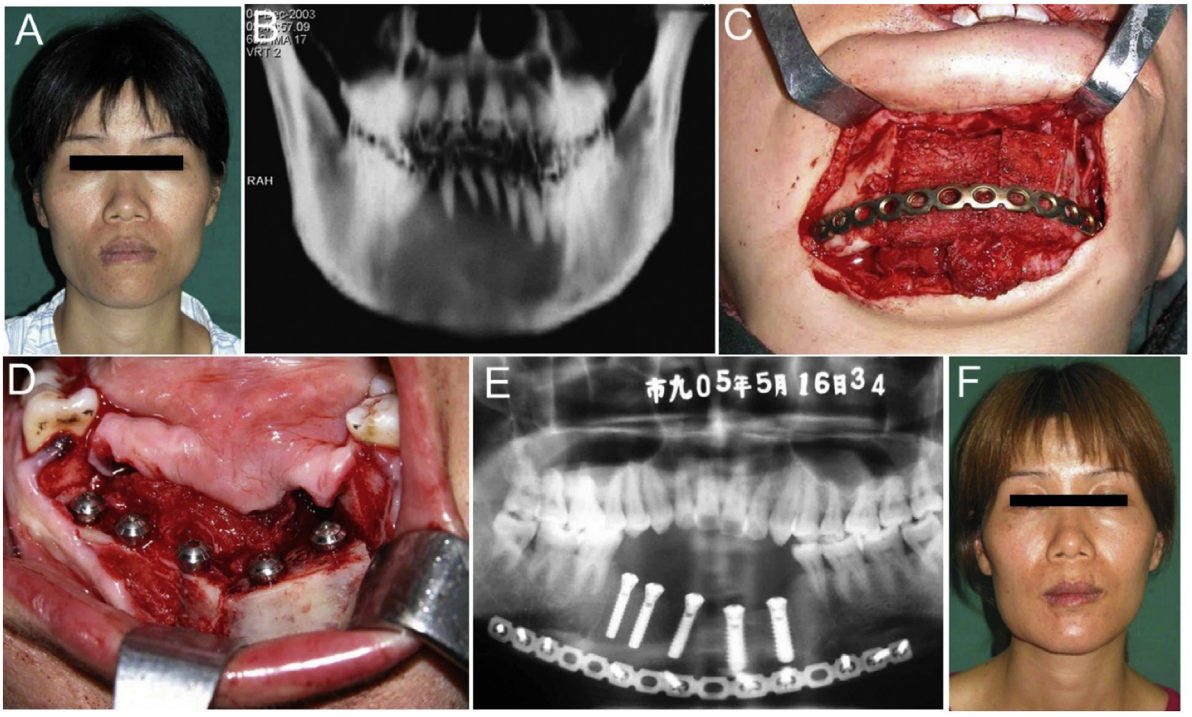

Fig. 2. A 35-year-old female patient with osteofibroma. (A) Facial photograph before surgery; (B) osteofibroma of the mandible; (C) mandibular reconstruction with a DCIA flap; (D) simultaneous dental implant placement; (E) panoramic radiograph and (F) facial photograph showing an excellent postoperative appearance and osseointegration of the dental implants.

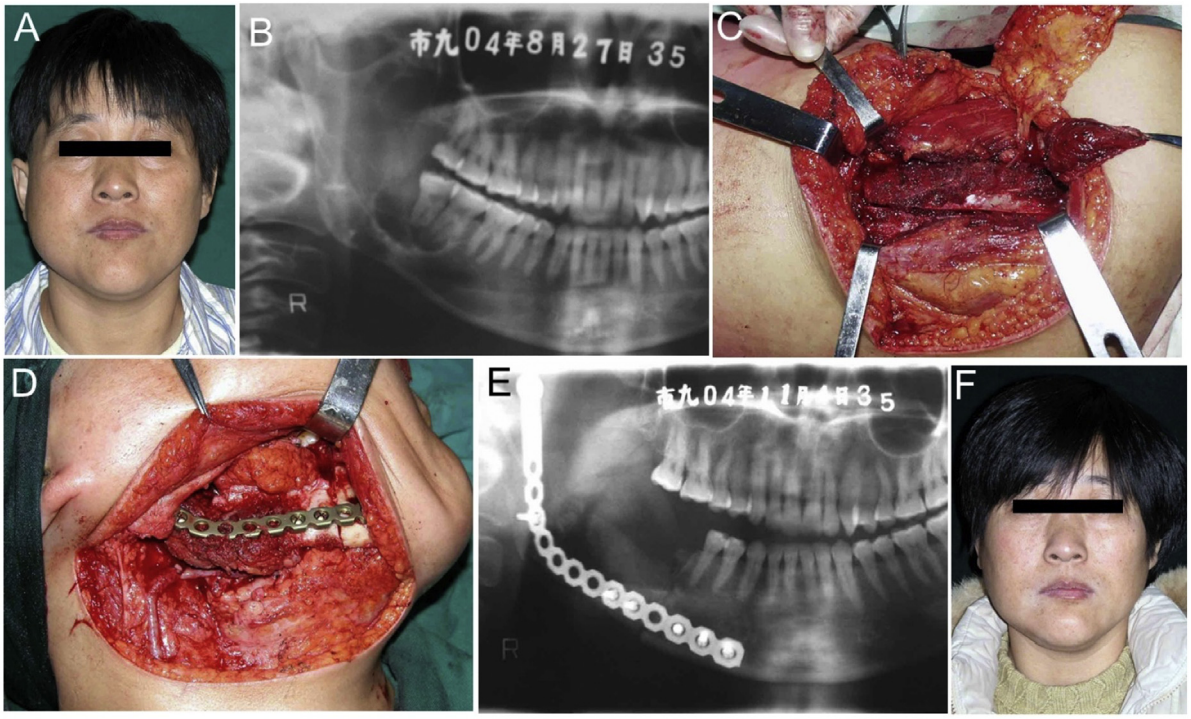

Fig. 3. A 42-year-old female patient with ameloblastoma of the left mandibular angle and ramus. (A) Facial photograph before surgery; (B) panoramic radiograph showing ameloblastoma of the left mandibular angle and ramus; (C) harvest of the scapula myocutaneous flap; (D) mandibular reconstruction with the scapula flap; (E) postoperative radiograph and (F) facial photograph showing an excellent postoperative appearance.

Table 2. Pathological diagnosis.

Pathological diagnosis	Cases, *n*	Proportion
Ameloblastoma	366	35.26%
Squamous cell carcinoma	278	26.78%
Osteoradionecrosis	152	14.64%
Osteofibroma	51	4.91%
Osteosarcoma	43	4.14%
Fibrous dysplasia of bone	32	3.08%
Myxoma	28	2.70%
Keratocystic odontogenic tumour	22	2.12%
Other sarcoma	17	1.64%
Osteomyelitis	14	1.35%
Other	35	3.37%
Total	1038	100%

Table 3. Arteries at the recipient site.

Artery at the recipient site	Cases, *n*	Proportion
Facial artery	596	57.42%
Superior thyroid artery	267	25.72%
Transverse cervical artery	77	7.42%
Lingual artery	31	2.99%
External carotid artery	24	2.31%
Unknown	43	4.14%
Total	1038	100%

Table 4. Veins at the recipient site.

Vein at the recipient site	Cases, *n*	Proportion
External jugular vein	447	43.06%
Common facial vein	263	25.34%
Facial vein	89	8.57%
Branches of internal jugular vein	81	7.80%
Anterior facial vein	64	6.17%
Posterior facial vein	13	1.25%
Superior thyroid vein	10	0.96%
Transverse cervical vein	6	0.58%
Anterior jugular vein	4	0.39%
Lingual vein	3	0.29%
Unnamed	58	5.59%
Total	1038	100%

patients (5.49%) had major complications requiring surgical intervention. The most common major complication was venous crisis, followed by haematoma; arterial crisis occurred less frequently than venous crisis. Postoperative necrosis occurred in 14 flaps, including 11 flaps associated with vascular crisis and one flap associated with local infection; the cause was not confirmed for two flaps. One patient was in a persistent vegetative state after pulmonary infection and one patient died of a pulmonary embolism (Table 5).

The incidence of vascular crisis was found to be much higher in the 187 patients who had received prior radiotherapy than in patients who had received no prior radiotherapy (Table 6). Of these 187 patients, eight had a venous crisis and three had an arterial crisis. Five flaps presented partial necrosis of the skin paddle and two DCIA flaps presented postoperative necrosis. There were five cases of local infection, three cases of pulmonary infection, and three cases of haematoma. The patient who died of a pulmonary embolism had received prior radiotherapy.

Discussion

Segmental defects of the mandible following the resection of malignant or benign tumours, trauma, and inflammation may impair the patient's swallowing, breathing, speech, and other oral functions. It may also result in catastrophic consequences for their facial appearance. The restoration of such defects was previously a challenging task for oral and maxillofacial surgeons. With the development of microsurgery, vascularized bone flap transfer has now become the standard method for reconstructing the mandible.

The fibula flap is the most common flap used to reconstruct the mandible, and its use has been increasing in recent years. The fibula can provide up to 25 cm of bone, and this flap is the only choice for defects of more than 10 cm in length[3]. In addition, the fibula flap has stable perforators to the skin paddle, which can be harvested in combination with the bone flap[4]. Due to the high volume of cortical bone, the fibula flap can bear higher masticatory forces than other bone flaps. Also, the flap harvest site for the fibula flap is distant from the main operation site in the head and neck region, allowing two surgical teams to operate simultaneously.

However, the fibula flap also has some disadvantages: (1) as the fibula is a long and almost linear bone, it is challenging to shape the bone flap to make it fit perfectly into the mandibular defect. Fortunately, this aspect of the procedure can be greatly simplified with the use of recently developed digital surgical techniques and guided cutting and modelling instruments[5]. (2) The bone height is too low to support dental implantation in Asian patients. Although this shortcoming can be overcome by the double-barrel technique, the length of the fibula eventually becomes limited[6]. The dental implant distractor (DID) was invented for simultaneous mandible reconstruction and dental implantation[7]. Postoperative distraction osteogenesis of the fibula bone can provide sufficient bone volume to support dental implantation. Up to 2017, 90 patients attending the Department of Oral and Maxillofacial–Head and Neck Oncology of Shanghai Ninth People's Hospital had received mandible reconstruction with a DID. (3) Harvesting the fibula flap with the peroneal artery will impair the blood supply to the foot in a minority of patients[8]. To avoid this risk, preoperative Doppler or computed tomography angiography (CTA) is necessary to determine whether the posterior tibial artery and peroneal artery arise from a common stem. There may also be donor site complications such as impaired stability of the ankle and the development of a claw-toe deformity[9]. These potential problems at the donor site should be discussed with the patient preoperatively, especially for young patients and athletes.

The vascularized iliac osteomyocutaneous flap is suitable for mandibular defects less than 10 cm in length, especially those involving the mandibular angle, because the shape of the anterior superior iliac crest is similar to the angle of the mandible and the iliac bone is sufficiently

Table 5. Complications[a].

Complications		Cases, *n*	Proportion
None		926	89.21%
Minor	Local infection	18	1.73%
	Pulmonary infection	11	1.06%
	Fistula	10	0.96%
	Partial necrosis of skin paddle	9	0.87%
	Wound dehiscence	9	0.87%
	Local effusion	6	0.58%
	Complications at donor site	4	0.39%
Major	Venous crisis	20	1.93%
	Haematoma	17	1.64%
	Flap necrosis[b]	14	1.35%
	Arterial crisis	8	0.77%
	Skin paddle necrosis	4	0.39%
	Bone flap displacement	3	0.29%
	Persistent vegetative state	1	0.10%
	Death	1	0.10%

[a] Of the 20 patients with venous crisis, one had a simultaneous local infection and one had a simultaneous pulmonary infection. Of the 17 patients with haematoma, one had a simultaneous local effusion. Of the 14 patients with flap necrosis, one also had a local infection and one had a fistula. Two of the eight patients with arterial crisis also had partial necrosis of the skin paddle. The patient in a persistent vegetative state also had a pulmonary infection. Of the 18 patients with local infections, other than those occurring simultaneously with venous crisis and flap necrosis, this also occurred in combination with local effusion in one patient and with fistula in two patients. One patient had simultaneous pulmonary infection and partial necrosis of the skin paddle.

[b] Flap necrosis: six due to venous crisis, five due to arterial crisis, one due to local infection, and two due to unknown reasons.

Table 6. Complications related to prior radiotherapy.

	Prior radiotherapy		No prior radiotherapy	
Complications	Cases, *n*	Proportion	Cases, *n*	Proportion
Total	187	100%	851	100%
Vascular crisis				
Venous crisis	8	4.28%	12	1.41%
Arterial crisis	3	1.60%	5	0.59%
Flap necrosis[a]	2	1.07%	12	1.41%
Wound healing				
Partial necrosis of skin paddle	5	2.67%	4	0.47%
Local infection	5	2.67%	13	1.53%
Haematoma	3	1.60%	14	1.65%
General complications				
Pulmonary infection	3	1.60%	8	0.94%

[a] Flap necrosis: the two cases of flap necrosis related to prior radiotherapy involved DCIA flaps.

high for dental implant placement. However, since the locations of the perforators on the skin paddle of the iliac bone are not constant anatomically, it should not be the first choice for the restoration of mandibular defects involving skin[10]. Conversely, the internal oblique muscle flap is preferred for the restoration of limited floor of mouth or gingiva defects. This flap also offers a soft tissue window for postoperative flap monitoring. However, the utility of this flap is somewhat limited as it requires healthy soft tissues to support the flap and seal the floor of the mouth. Thus, it is contraindicated in patients with prior radiotherapy or combined defects of mucosa and skin. Internal oblique muscle defects may weaken the abdominal wall and increase the risk of abdominal hernia, especially in nulliparous female patients.

The scapula bone flap is not used as commonly as the above two flaps, as the harvested scapula bone is too thin for dental implantation, rendering it suitable only for ramus reconstruction. Also importantly, the patient is required to be in the prone position during flap harvesting, making it impractical to perform simultaneous surgery in the head and neck region, and the pedicle length is relatively shorter compared with other flaps. Thus, the scapula flap is generally used for the restoration of extensive skin defects due to the availability of soft tissues.

There are many factors to consider in choosing a vessel for the pedicle. Very often, either the facial artery or the superior thyroid artery is preferred, and the transverse cervical artery and lingual artery can also be considered if the above two vessels are unavailable or unsuitable. Under some extreme conditions, the external carotid artery may be used for end-to-end or end-to-side anastomosis. However, there may be a difference in diameter between the donor and recipient vessels. Given the high blood pressure of the external carotid artery, additional problems may arise, such as blood vessel leakage and imbalances between the arterial supply and venous drainage, making it risky to choose the external carotid artery.

It is particularly critical to choose an appropriate artery in patients who have undergone adjuvant radiotherapy, as the radiation may make the vascular wall more fragile. In the authors' experience, it is preferable to choose a deeply situated artery far away from the radiation zone in order to minimize the risk of vessel damage caused by radiation. The superior thyroid artery and lingual artery are our first choice, both of which are deeply situated in the radiation zone and can be identified easily. Considering the quality of vessels at the recipient site, the transverse cervical artery and the contralateral superior thyroid artery may also be considered, in descending order of preference. The choice of vessels in patients who have undergone prior radiotherapy has also been described in a previous study performed at Shanghai Ninth People's Hospital[11].

For patients with prior radiotherapy, a common practice is to first identify a suitable artery and vein at the receipt site and then choose an ipsilateral or contralateral bone flap for harvest. The choice of vein is as important as the choice of artery, and the vein must be placed smoothly without kinks, especially in the anastomotic region. The EJV was the most common choice in this study, due to the constancy and predictability of its anatomical position, which makes it easy to identify intraoperatively and monitor after the operation. However, the EJV is close to the skin surface, making it more likely to be compressed postoperatively and sacrificed if the patient has to undergo neck dissection. The second most common choice of recipient vein was the common facial vein and other major branches of the internal jugular vein. Although their anatomical positions are not as constant as

Table 7. Flap monitoring protocol.

	Observation index[a]	Normal	Abnormal	Description if abnormal
Routine observation	Colour	☐	☐	
	Morphology and texture	☐	☐	
	Temperature	☐	☐	
Test if necessary	Capillary refill test	☐	☐	
	Acupuncture bleeding test	☐	☐	
	Doppler	☐	☐	

[a] Colour: normal, ecchymosis, purple or pale. Morphology and texture: normal, swollen, or shrunken. Temperature: normal, a little lower than the surrounding skin, or cold. Capillary refill test: <2 seconds, 2–5 seconds, or >5 seconds. Acupuncture bleeding test: normal, dark red blood, or no bleeding.

Table 8. Frequency of flap observation.

Time point postoperative	Frequency of flap observation
Within 3 days	Hourly
3–5 days	3-hourly
5–7 days	8-hourly (06:00, 14:00, 22:00)
After 7 days	Daily

that of the EJV, the branches of the internal jugular vein are deep in the neck, making them less prone to compression. Given the higher blood flow rate than in the EJV, they are also less likely to develop thrombosis. In several cases without other suitable veins, the pedicled cephalic vein was used as the receipt vein.

The most common major complications were vascular crisis and haematoma, which require exploration as soon as possible. Venous crisis was more common than arterial crisis due to the much slower venous blood flow rate, but patients with arterial crisis were more likely to develop necrosis[12]. Of the 20 venous crisis cases, 14 were salvaged and six developed necrosis, while of the eight arterial crisis cases, three were salvaged and five developed necrosis. Venous crisis is commonly caused by torsion, partial compression, haematoma, inappropriate drainage tube, and differences in diameter between donor and recipient vessels. In the majority of cases, a skin island was left as visible tissue for monitoring flap viability, even in those with no intraoral mucosal defects. The monitoring protocol is outlined in Table 7.

Venous crisis could be observed at an earlier stage, because it is easier to observe a flap turning purple than to observe a flap turning pale, which is characteristic of an arterial crisis. Sometimes ecchymosis was found on the skin paddle even when the vascularity of the pedicle and bone flap appeared viable. In such cases, the perforator could be compressed or kinked, and the skin paddle could have partial or total necrosis. Such flaps were then debrided and additional soft tissues were required to cover the wound. The colour change of the skin is the most obvious indicator of flap condition, and the morphology texture and temperature can also offer important information about the flap condition. In some cases, additional tests such as the capillary refill test, acupuncture bleeding test, or Doppler were needed. The frequency of flap observation is listed in Table 8.

Once a vascular crisis has occurred, prompt intervention will ensure a higher success rate of flap salvage, and hesitation or further monitoring will only prolong the ischemia time of the flap, resulting in flap loss. The exploration procedure is shown in Fig. 4. In the authors' experience, the success rate is relatively high if an intervention is performed within 5 h of vascular crisis. However, it may take a few hours for flap ischemia to become clinically evident, making it difficult to perform a further intervention within 5 h of vascular crisis. In this study, there was no time for flap salvage in 11 cases of flap necrosis due to vascular crisis. Therefore, it is crucial to monitor the flap at an appropriate frequency postoperatively. In addition, haematoma should also be explored.

Of the 14 cases of flap necrosis, six were iliac flaps and eight were fibula flaps. There was a relatively lower necrosis rate for the fibula flap compared to the iliac flap. An important reason for this is that most harvested DCIA flaps had no skin paddle and thus no monitoring window, and the defect in the oral cavity could not be healed as tightly without a skin paddle, leading to relatively higher local infection and necrosis rates. However, as the fibula flap was commonly used for extensive mandible defects, the bone flap was osteotomized into several segments. During the osteotomy, an inexperienced surgeon might strip the periosteum excessively

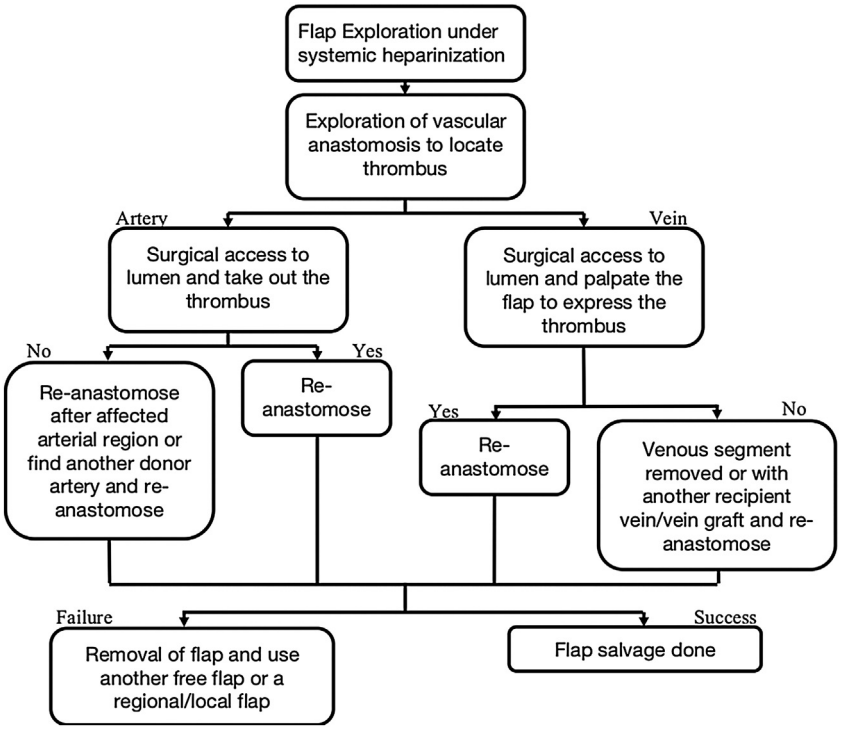

Fig. 4. Exploration procedure.

or damage the vascular pedicle. Care should also be taken in vascular pedicle placement using the double-barrel technique to prevent any flow impediment. All of these factors could increase the incidence of vascular crisis or flap necrosis in the fibula flap.

Other complications requiring exploration include wound dehiscence and fistula. In order to avoid these complications, the mucosa should be sewn tightly and kept tension-free, and there should be sufficient soft tissue coverage of the surface of the bone flap. In the authors' experience, the most susceptible place is the cross ridge of the mandible alveolar crest and graft bone. Once wound dehiscence has occurred at the ridge, allowing saliva to permeate in between the mandible and the bone flap, the risk of bone malunion and infection becomes much higher.

Pulmonary infection was the most common systemic complication. The operation decreases the patient's immunity and thus a tracheotomy might be a major risk factor for infection. When the mandibulectomy involves the chin or ramus, retraction of the tongue or local swelling might cause a disturbance of ventilation. As a result, most such patients require a tracheotomy, resulting in an increase in the incidence of pulmonary infection. Deep venous thrombosis (DVT) is another possible systemic complication, as patients are strictly confined to bed for up to 5 days immediately after the operation. The complications of DVT and pulmonary embolism, for example, could be fatal and difficult to salvage. Of the 1038 patients included in this study, one died of a pulmonary embolism.

A one-stage operation is considered the best choice whenever possible for patients with ameloblastoma and for other benign lesions where resection is indicated. It has several advantages, such as lower operative site morbidity, lower cost, no time constraints, and no additional operations and hospitalizations. Virtual surgical planning can be used to improve the precision of reconstruction and avoid the negative impacts of the postoperative movement of the mandible stump. However, in the Department of Oral and Maxillofacial–Head and Neck Oncology, Shanghai Ninth People's Hospital, there is controversy regarding whether one-stage mandible reconstruction may result in a higher recurrence rate for these malignancies.

Most patients with a malignancy needed postoperative radiotherapy, resulting in high-dose radiation in the field of the bone flap. This radiation may impair bone union and even result in bone flap necrosis in the worst cases. Therefore, a soft tissue flap such as the anterolateral thigh (ALT) flap is usually used to cover the defect instead of bone reconstruction. However, this results in the remnant native mandible being displaced under the unequal traction of the masticatory muscles. This is especially evident if the defect is left with only soft tissue reconstruction using an ALT flap for a prolonged period of a few years. Reducing the dislocated mandible into its proper place once displacement has occurred is particularly challenging, due to the residual fibrosis at the operative site and remodelling of the musculature. Orthognathic surgery may be needed to correct the mandibular position.

In cases where the defect involves the body of the mandible, especially those crossing the midline, it is crucial to choose a reconstructive method that can maintain the soft tissue in order to ensure the aesthetic appearance of the chin. Hidalgo suggested the use of three-segment mandible reconstruction, in which one segment of fibula flap is used to reconstruct the mandibular body[13]. Although this is easy to complete, it may result in a square jaw appearance and a loss of chin projection, making it unsuitable for the oriental face. Matros et al. presented a five-segment method that corresponded better with the profile of the mandible[14]. However, the incidence of segment ischemia would be higher with this method, and the surgical technique is more complicated. A four-segment mandible reconstruction technique based on the mandible shape of Asians has been used at Shanghai Ninth People's Hospital, in order to better satisfy the aesthetic requirements of these patients[15]. In contrast to the five-segment procedure, it is easier to shape the flap with this technique, and the risk of segment ischemia is reduced because all segments have a minimal length of 1.5 cm[16]. Furthermore, one of the authors (ZCP) has designed a fibula osteotomy guide to determine the position and angulation of each osteotomy for total mandibular defects, and thus the surgical procedure can be simplified and the precision can be improved[15]. For dental implantation, a four-segment jaw reconstruction is superior to a three-segment jaw reconstruction, which is unsuitable for the dentition shape.

In conclusion, the free vasularized bone flap should be considered as the first choice of treatment for oromandibular reconstruction due to the low failure rate in most cases, particularly those with large bone defects requiring multiple osteotomies. For Asian patients, we recommend four bone segments to restore the whole body of mandibular defects.

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Competing interests

None declared.

Ethical approval

Ethical approval was given; the relevant judgement reference number is Ninth People's Hospital 2016-106.

Patient consent

Patient consent was obtained to publish the clinical photographs.

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