Repair and Reconstruct of Mandibular Defects

9

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1 Overview

The oral and maxillofacial region is one of the main factors that constitute the human facial appearance. The mandible is located in the lower one third of the face, and it has a major impact on the appearance characteristics of the person. The facial appearance plays a major role in the human body shape, and a small change in facial appearance can cause the attention of other people. The mandibular defect occupying the lower one third of the face will cause marked facial deformity, in addition to the appearance of damages in a series of physiological functions, and the patient will suffer from diminished quality of life due to varying degrees of disfigurement. All kinds of social activities of the patient will be seriously affected, which will lead to varying degrees of psychological trauma.

The mandibular defects caused by head and neck tumor surgery are often accompanied by defects in surrounding soft tissues such as the floor of the mouth, tongue, and buccal area. The impact on the chewing function occurs at first. A change in pronunciation and the digging language will be resulted due to the lack of coordination of the surrounding soft tissue, and the swallowing, sucking, and respiratory functions will be affected to varying degrees. The composite tissue defects in the lower face have a greater impact on the facial appearance of the patient, and thereby the psychological and mental traumas are very serious. Therefore, high attentions must be paid to the repair and reconstruction of the mandible. During treatment, we should consider not only the functional reconstruction of the mandible and relevant tissues but also pay attention to the improvement and repair of the facial appearance, try our best to apply the existing technologies in maxillofacial surgery and plastic surgery to make each patient get perfect repair and reconstruction, and lay a good foundation for their future reintegration into society.

For the repair and reconstruction of the mandible, one of its main contents is to reconstruct the occlusional relationship. If the occlusional relationship is not repaired and reconstructed, only partial recovery of appearance and function is achieved in patients after mandibular reconstruction. The lack of occlusional relationship will cause the loss of chewing function on the one hand; on the other hand, the facial soft tissues will have a different degree of invagination due to the lack of support of the teeth, and it makes the face look older than the actual age. Therefore, the repair and reconstruction of the mandible not only aim to restore mandibular continuity and integrity but also must establish conditions for denture retention, bearing the bite force, and performing chewing function, in order to restore the physiological function of the oral cavity. In clinics, the buccal labial sulcus and the hyomandibular canal in local area often become shallow or disappear after repair and reconstruction of the mandible, the alveolar crest is missed, or the height of the reconstructed mandible is inadequate; all these cause difficulties to oral denture restoration, and the chewing function cannot be recovered effectively. Since the 1970s, the scholars at home and abroad have carried out the denture restoration successively which takes the endosseous implant as the retention and bearing foundation. In addition, in order to increase the height of the reconstructed mandible, the continuous innovations in surgical techniques are pursued, so that the technological level of repair and reconstruction of the mandibular defect is increasingly improved and the dual purposes of appearance recovery and functional reconstruction are achieved to a large extent. Therefore, it is very necessary to develop and popularize the technologies for repair and reconstruction of the mandible in surgical oncology clinics, and it can benefit the majority of cancer patients [1–9].

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1.1 Classification of the Mandibular Defects

To facilitate the gradient classification of mandibular defects caused by tumor and trauma and the statistical analysis of follow-up data, and facilitate guiding clinical treatment at the same time, a number of scholars at home and abroad have put forward a variety of different classification methods for mandibular defects since the 1980s.

The classification methods which are more commonly used in foreign countries include HCL [7] and CRBS [27] classification methods. Many domestic scholars have presented different classification methods from different angles, of which Zhang Chenping put forward a new functional classification method for mandibular defects characterized by functional zoning.

Zhang Chenping et al. divided the mandibular defects into three classes according to the frequency of occurrence of mandibular defect:

1. Class I defects: The defects which are limited to the mandibular body (occlusion area)
2. Class II defects: The defects in muscle area – occlusion area
3. Class III defects: The defects in condyloid process – muscle area – occlusion area

Three classes of mandibular defects all have two subclasses 1 and 2: I1, alveolar defects; I2, the segmental defect in occlusion area; II1, the defects in coracoid area; II2, the segmental defect in muscle area; III1, the defects in condyloid process; and III2, the defects in condyloid process and muscle area.

To further refine the description of defects in occlusion area, it is stipulated that the occlusion area is divided into two tooth position areas such as anterior tooth position area and posterior tooth position area; a (anterior) represents three tooth positions in anterior tooth area, and p (posterior) represents three tooth positions in posterior tooth area, namely, the bilateral occlusion areas which are divided into four quadrants. In this way, the defect record of the defects in bilateral occlusion areas can be expressed as pa-ap, and "-" indicates crossing the midline. In addition, in order to reflect the defect morphologies in jaw-lifting muscle group and adjacent organs such as the lips and tongue, it is stipulated that the italic letters m (muscle group), l (lip), and t (tongue) indicate the defect morphologies in the jaw-lifting muscle group, lips, and tongue and are labeled respectively at the end of the abovementioned classifications.

This classification method can relatively comprehensively reflect the morphologies of mandibular defects, which is conducive to clinical comparative studies while helping to choose different reconstruction methods.

1.2 Indications, Objective, and Preoperative Preparation for Repair and Reconstruction of Mandibular Defects

1.2.1 Indications

In the field of repair and reconstruction of defects after head and neck tumor surgery, the repair and reconstruction of mandibular defects have been one of the focuses. Before carrying out the microsurgical techniques, the repair and reconstruction of mandibular defects have been at a low level. As technology advances, the technological level of repair and reconstruction of mandibular defects has been greatly improved, the mandibular reconstruction which needed to be completed by multiple operations in the past is now basically completed at one time, and both the appearance and function after reconstruction have a qualitative leap compared with before. For surgical treatment of malignant tumors in head and neck soft tissue or the mandible, due to the development of the microscopic technology, the surgeons are no longer worried about the difficulties in repair of oral and maxillofacial defects; therefore, the surgical safety margin is more assured compared with that in the past, and the surgical indications for mandibular reconstruction are also greatly expanded.

Currently, it is basically advocated that the immediate repair and reconstruction of intraoperative defects of the mandibular benign tumors are performed with different approaches. The controversial issue in indications for repair and reconstruction of mandibular defects is mainly whether the defects after malignant tumor surgery are repaired at the same period. The conventional wisdom holds that the patients should be observed for 2 years and, if no recurrence occurs, the repair and reconstruction will be performed; but along with the viewpoint of ensuring the quality of life getting accepted, more and more scholars approve the viewpoint that one-stage reconstruction is performed intraoperatively. After all, both the appearance and function in patients undergoing repair are much better than those in patients without undergoing repair or with other alternative products. One-stage simultaneous reconstruction has obvious advantages compared with second-stage reconstruction, which are mainly reflected in the following aspects:

1. There is no apparent scar tissue.
2. The local vascular conditions are good, which is conducive to microsurgical operation.

3. The position of the mandible has no significant change, which will help reestablish the occlusional relationship.
4. It is much easier to recover the appearance and function before the patients fall ill.

But the premise is that there must be enough safety margins in tumor resection and the patients can withstand long-time operation.

1.2.2 Objectives of Repair and Reconstruction

1. The continuity of the mandible is restored.
2. The occlusional relationship is reestablished at the same time or second stage, and the dentition is reconstructed.
3. The bone and soft tissue profile and the normal anatomical landmarks in the lower one third of the face are reconstructed.
4. The physiological functions such as chewing, swallowing, and breathing and other physiological functions are restored to improve the quality of life.

From the functional point of view, restoring the continuity of the mandible is very important, because the mandible is the support structure of soft tissues such as the mouth floor, lips, and tongue. Once the mandible is lost, there will be occurrence of various degrees of functional disorders, such as chewing, swallowing, and articulation disorders. From the viewpoint of the facial appearance, because the osseous mandible and the adjacent tissues jointly form the lower one third of the face, the relationships between the nose, lips, and mandible constitute one of the main features of facial appearances of individuals, and restoring the continuity of the mandible will help to restore the facial symmetry and balance, while the osseointegration implant or postoperative buccal gingival sulcus plasty is applied in the denture repair to restore the chewing function of the patient and also improve the recovery of the facial appearance.

1.2.3 Preoperative Preparation

The radical resection of oral mandibular malignant tumor is often accompanied by adjacent soft tissue defects, the soft tissue repair performed at the same period is crucial to restore the appearance of soft tissues and ensure the healing of reconstructed mandible, and the preoperative comprehensive consideration should be carried out from the perspectives of the head and neck surgery and the repair and reconstruction of oral and maxillofacial area [9–12].

The repair and reconstruction of defects after mandibular tumor resection are a delicate operation, which requires that the operators not only have good microsurgical techniques but also have good aesthetic point of view, grasp the structural characteristics of normal facial appearance, and have a more in-depth understanding on the concept of the occlusional relationship. At the same time, it is also needed to make evaluations on the patient's medical history, the general condition and range of local lesion, and the intraoperative defect statuses of soft tissues and bone tissues, in order to understand whether it is needed to simultaneously perform the repair and reconstruction of defects with other soft tissue myocutaneous flaps [2, 12–17]. The operators must have a clear understanding of the situation of blood vessels in receptor site and prepare well accordingly.

The preoperative preparations include the further examinations of the general condition of the patient, such as heart and lung function, surgical tolerance indicator inspection, and the exclusion of distant tumor metastasis. At the same time, the mandible panoramic radiograph and CT examination must be carried out before surgery, and the two imageological examinations are the bases to determine the range of the mandible resection. The soft tissue surrounding the mandible can be evaluated by MRI to better determine the resection range of the soft tissue. At the same time, attentions should be paid to the patient's oral hygiene, and the patients with poor oral hygiene may undergo periodontal scaling before surgery. While the situations of the temporomandibular joint, the full mouth dentition, and the occlusional relationship should be examined, the appropriate preparation should be made for edentulous patients before surgery, such as temporary retention plate. For difficult cases with mandibular displacement, CAD/CAM technology can be used to prefabricate personalized mandible models of the patients, so that the reconstructed mandible is coordinated.

2 Application of Vascularized Osseo-myocutaneous Flap in Mandibular Reconstruction

The bone transplantation is a method mostly used in repairs and reconstructions of various types of mandibular defects. The experimental study and clinical application of the bone transplantation have a history of nearly 200 years. Although greater progresses have been made in aspects such as the understanding of the biological physiology of bone transplantation, the concepts of immunology of bone graft, the treatment and preservation of allogeneic bones, the application of heterogeneous materials and the improvement of surgery, and the repair and reconstruction of function and appearance for patients with mandibular defects and have obtained more satisfactory results, the complications such as delayed union, nonunion, and bone resorption still exist in many aspects, which are not satisfactory. In the early 1980s, the development of microsurgical techniques and the clinical application of vascularized bone transplantation symbolized that the mandibular defect repair had entered into a stage of functional repair. The vascularized transplantation has advantages that it can repair large complex defects at one stage, is not subject to the constraint of the blood vessel condition in receptor site, and has strong resistance to infection, less transplanted bone resorption, and strong biological and mechanical properties, so that the indication range for bone transplantation is continuously expanded. Therefore, we can say that vascularized bone transplantation is a milestone in the treatment of mandibular defect.

For the donator selection for the bone transplantation, the autogenous bone transplantation is still the bone transplantation most widely used in mandibular reconstruction. The fibula and ilium are the main bone donor sites, and in addition, there are also the ribs, tibia, scapula, mandible, and skull. The autogenous particulate marrow-cancellous bone transplantation and the replantation of frozen autologous diseased bone also have been applied in clinical practice. In recent years, the tissue-engineered bone also has been tried in clinical practice and has achieved preliminary results. Under some circumstances, the heterogeneous materials such as titanium reconstruction plate still have a useful value. However, among a variety of methods, the vascularized autologous bone transplantation is still the main method for mandibular reconstruction [18–26]. In this article, the authors will make a brief introduction to some methods commonly used in clinics at present.

2.1 Application of the Iliac Osseo-myocutaneous Flap in Mandibular Reconstruction

The iliac osseo-myocutaneous flap plays a very important effect in repair and reconstruction of mandibular defects, and it is one of the donor sites which are most commonly used at present. Manchester firstly reported that the shape of curved front part of the ilium was very similar to the shape of the unilateral mandibular body and, because of its adequate bone mass, it became the most commonly used donor site of non-vascularized bone block and cortical cancellous bone in the early stage. In 1979, the researches performed respectively by Taylor from Australia and Magou from the United Kingdom confirmed that the deep circumflex iliac artery (DCIA) and the deep circumflex iliac vein (DCIV) were the most reliable vascular pedicles for vascularized iliac transplantation. The research of Taylor indicated that the deep circumflex iliac artery and vein system provides blood to the entire ilium and periosteum and its range is from the anterior superior iliac spine to the sacroiliac joint. DCIA also provides blood to the skin on the surface of the ilium. In 1984, the research of Ramasamy indicated that the ascending branch of DCIA was the main blood vessel supplying blood to the obliquus internus abdominis muscle and thereby the modified iliac osseo-myocutaneous flap occurred. Its main characteristic is that, in addition to the iliac bone flap, the internal oblique muscle flap is also included and the single pedicled two skin flaps can be formed in most cases. The mobility of the muscle flap is better, which is very beneficial for repair and reconstruction of oral and maxillofacial soft tissue defects.

2.1.1 The Applied Anatomy

The ilium is located in the upper part of the hip bone and is a fan-shaped irregular bone. It is mainly consisted of cancellous bone, and its surface is thinner cortical bones. The ilium is divided into the hypertrophic iliac body in the lower part and the abducent and flat wide iliac ala in the upper part. The iliac body mainly constitutes the acetabulum and participates in the composition of the hip joint; the lower posterior side of the iliac ala is the rough auricular surface, which participates in the composition of the sacroiliac joint. The upper margin of the iliac ala is fat and thick, slightly arched, and called as the iliac crest, its front and rear ends are thicker, and the middle part is slightly thinner. The morphology of the iliac crest is similar to that of the lower margin of mandible. The anterior part of the iliac crest protrudes toward the lower anterior side and is known as the anterior superior iliac spine (ASIS). ASIS is attached to the inguinal ligament, sartorius muscle, and tensor fasciae latae muscle. Close to the body surface, the tubercle of iliac crest is the protuberance at 5–7 cm from its posterior side, so it is the preferred donor site of the free bone grafts due to its flat surface and the thick cancellous bone. The posterior end of the iliac crest is the posterior superior iliac spine (PSIS). In adults of China, the average length between ASIS and PSIS is 24.4 cm (20.1–28.8 cm). The range for bone harvesting in clinics is generally within 10–12 cm backward from ASIS, so as to avoid damage to the posterior part of the iliac ala which can affect the stability of the sacroiliac joint.

The inner surface of the iliac ala is a shallow nest which is known as iliac fossa, and it is the attachment site of the iliac muscle. DCIA and DCIV run at the medial side of the iliac fossa. The lower boundary of iliac fossa is a blunt round bone crest, which is called as the arcuate line, and is the bony boundary between greater pelvis and small pelvis. The outer side of the iliac ala is the gluteal surface, which is attached to gluteus. The upper half of the lateral gluteus maximus muscle, gluteus medius muscle, the piriformis muscle, and gluteus minimus muscle in the underneath and the musculus iliacus at the medial side are mainly involved in the movements of the hip joint. The front end of the iliac crest is attached to the tensor fasciae latae muscle and the sartorius muscle; the former is participated in the movements of the hip joint; the latter stops at the tibia and is participated in the movements of the knee joint. After bone harvesting, these muscles should be put back to their original place and sutured to avoid affecting the activities of the abovementioned joints. The upper part of the iliac crest is attached to the abdominal muscles, which are the abdominal external oblique muscle, abdominal internal oblique muscle, and transverse abdominal muscle, respectively, from the shallower to the deeper. The anterior end of the iliac crest is the end point of inguinal ligament consisting of aponeurosis transmigrated from the muscles, and the posterior end of the iliac crest is attached to the latissimus dorsi fascia. Of which the abdominal internal oblique muscle is usually used in combination with the iliac bone flap to repair the composite head and neck defects. The abdominal internal oblique muscle is the flat wide muscle located between the abdominal external oblique muscle and transverse abdominal muscle; starts from the thoracolumbar fascia, iliac crest, and inguinal ligament; and is attached to the tenth to twelfth rib muscles and the sheath of rectus abdominis muscle. The ascending branch of DCIA is its main blood supply, and in addition, it also receives the blood supply from the inferior epigastric artery, the lumbar artery, and the branch of thoracic artery. The diameter of the ascending branch given off from DCIA is 1–2 mm, which passes through the transverse abdominal muscle to reach the deep surface of the abdominal internal oblique muscle. According to related studies, it is found that the abdominal internal oblique muscle in about 80% of persons is supplied with blood from a main blood vessel given off from the medial side of the ASIS and therefore the abdominal internal oblique muscle can be used as an axial pattern flap to operate; the remaining 20% of persons have no separate branches, but only some small branches at the outer side of ASIS enter into abdominal internal oblique muscle, and in the operation, the muscle can only be attached to the inner table of the iliac crest.

DCIA is given off from the outer side of the external iliac artery above the inguinal ligament, and the inferior epigastric artery is given off below it. DCIA runs toward the outer upper side between the abdominal muscle and the iliac muscle, and it, namely, runs within the fiber channel fused by the transverse abdominal muscle membrane and fascia iliaca, with a distance of 0.4–2.2 cm from the inner side of the iliac crest. It gives off multiple perforating branches along the way to feed various layers of abdominal muscles and the iliac crest, and its terminal branches are anastomosed with the iliolumbar artery and the fourth lumbar artery. The diameter of DCIA is 2–3 mm. The length from the connection point of the external iliac artery to ASIS is 5–7 cm. The initial part of DCIA varies greatly; the highest point reaches up to 1.3 cm above the inguinal ligament, and the lowest point reaches down to 2.4 cm below the inguinal ligament (i.e., originating from the femoral artery).

DCIV is usually composed of two accompanying veins, which are merged into one DCIV before meeting the external iliac vein, and accompanies the DCIA in the inguinal ligament. The femoral vein is constantly located in the medial side of the femoral artery.

According to the running direction of DCIA and the situation of giving off perforating branches along the way, when the iliac bone flap is prepared, attention must be paid to retaining the myocardial sleeves of the abdominal external oblique muscle, abdominal internal oblique muscle, and transverse abdominal muscle where the perforating branches pass through, that is, to retain the myocardial sleeves within 3 cm from the inner table of the iliac crest and keep away from the abovementioned perforating branches.

Meanwhile, the area for flap harvesting mainly involves the iliohypogastric nerve, the ilioinguinal nerve, the lateral femoral cutaneous nerve, and the femoral nerve, which are mixed nerves issued by the lumbar plexus. The former three nerves mainly control the movements of the abdominal muscles and the cutaneous sensation in the lower abdomen and inguinal area and at the anterolateral side of the thigh and the lateral hip. After they are injured, the main performances are presented as the decreased muscular tension in inguinal area and reduced cutaneous sensation in corresponding areas. The femoral nerve in the deep surface of the inguinal ligament travels at the lateral deep surface of the femoral artery and participates in movements of hip and knee joints and the cutaneous sensation in the leg. Therefore, the operators must have a clear understanding on the running directions of these nerves to facilitate intraoperative identification and protection.

2.1.2 Design and Application

Since the anatomical characteristics of the iliac crest are similar to those of the mandible in many respects, and the cancellous bones are rich, it is more commonly used for repair of the mandibular segmental defect at one side.

Currently, the iliac bone flaps mainly include nonvascularized iliac bone flap, free vascularized iliac bone flap, and the iliac osseo-myocutaneous flap with the abdominal internal oblique muscle or transverse abdominal muscle or skin. When the skin flap is designed in clinics, the following factors should be considered according to the specific circumstances: (1) these include designs of incision, bone flap, and muscle flap and the location and shape of the flaps; (2) for the vascularized osseo-myocutaneous flap, the running direction of vascular pedicle must be considered at first; and (3) when the skin incision is designed, the medial side above the inguinal ligament at the femoral pulse point can be taken as the starting point of the incision, and the incision runs upward and presents as S-shaped curve and reaches to the site for bone harvesting.

If it is needed to prepare an osseo-myocutaneous flap, the blood vessel characteristic of the flap must be considered at first, because its blood supply comes from the myocutaneous perforators of DCIA, and the direction of the flap must be parallel to the inner margin of the iliac crest to ensure that a sufficient number of myocutaneous perforators are included. The island is usually designed as spindle shaped to facilitate direct suture closure of wounds. In addition, in order to ensure the blood supply to the skin island, it is required to retain 3 cm wide of abdominal internal and external oblique muscles and transverse abdominal muscle between the iliac crest and the flap as muscle sleeves. According to our experience, after such a bloated flap is placed in the mouth, almost all patients will require a second surgery. Therefore it is best applied for repair of defects combined with extraoral skin defects.

Generally, the length of the iliac bone flap is determined based on the mandibular body defect. The length of iliac crest bone graft is generally 11–12 cm, and the longest is no more than 15 cm, so as to prevent the occurrence of significant complications in donor site. The height of bone flap is usually within 2–3 cm; if necessary, the bone flap is cut off from the lateral surface and is reshaped to recover the appearance of the mandible; and the cancellous bones must be filled into split bone seams to prevent the occurrence of nonunion.

If it is needed to repair the mandibular ramus with processus condyloideus, the iliac skin flap can be designed to be L-shaped. If the ipsilateral iliac bone is harvested, the mandibular ramus can be designed in the anterior end of the bone flap, and ASIS can be reconstructed into the shape of the lower oblique angle and also can be retained. To avoid the deformity and dysfunction in donor site caused by the excessive defects in the anterior end of the iliac crest, the contralateral iliac bone can also be harvested, the mandibular ramus can be designed in posterior end of the bone flap, and the height of the mandibular ramus is determined based on the defect, usually downward to 4–6 cm below the upper margin of the iliac crest. Attentions must be paid to trying not to strip off too much muscle attachments.

2.1.3 Preparation of the Internal Oblique-Iliac Crest Flap

The general preparation is the same as that for the abovementioned iliac bone flap. An S-shaped incision from the medial side of the femoral artery pulse point to the iliac crest is made, and if the cutaneous flap is harvested at the same time, the connecting line between ASIS and the inferior angle of scapula can be taken as the central axis to design the skin flap including main myocutaneous perforators. The skin, subcutaneous tissue, and abdominal external oblique muscle and its aponeurosis are incised, and 3 cm width of muscle tissue is retained and connected to the iliac crest to protect myocutaneous perforators. Subsequently, the abdominal external oblique muscle is turned over to the costal margin level to expose the entire abdominal internal oblique muscle. The size of the muscle flap is designed according to the size of defects in receptor site, and the abdominal internal oblique muscle is incised and turned over from the surface of the transverse abdominal muscle. Near the 12th rib, the plane between the abdominal internal oblique muscle and the transverse abdominal muscle are most easily identified and separated, because the direction of the muscle fiber is different between the two muscles. The operation must be carefully performed at the plane to fully lift up the abdominal internal oblique muscle, the integrity of the transverse abdominal muscle must be maintained in this process, while the dissection is carefully performed to identify and protect the ascending branch of DCIA and the nerve vessel bundle across the plane from the outside to the inside. The terminal branches of the subjacent nerve vessel bundles are intertwined together, with the ascending branches, and thus must be cut off. The ascending branches of DCIA are visible at the deep surface of the abdominal internal oblique muscle, the trunks of the ascending branches pass through the transverse abdominal muscle and then converge into DCIA and DCIV, and whereafter, DCIA and DCIV are dissected to the site of the external iliac blood vessel. At the moment, the iliac muscle and the lateral femoral cutaneous nerve can be exposed. DCIA and DCIV travel within the fibrous sheath formed by the fusion of the transverse abdominal muscle and iliac fascia sheath fibers. A 2 cm muscle sleeve should be retained at the inner table of the ilium to protect them. After the operation in medial side of the ilium is completed, the dissection in outer side of the ilium can be performed. The outer table of the ilium is sharply dissected for osteotomy, while the lateral femoral cutaneous nerve is dissected in the vicinity of ASIS and is protected. The iliopsoas muscle and sartorius muscle at the medial side of the ilium are carefully cut off. After dissection and separation are completed, the abdominal contents, DCIA, and DCIV are well protected.

If the abdominal internal oblique muscle is supplied with blood by a single ascending branch, it can be incised parallelly through the iliac crest to vascular ascending branch from outside to inside, and thus the abdominal internal oblique muscle flap can be further dissociated. At the same time, attention should be paid to retaining 3 cm width of lateral myocardial sleeves to avoid damage to the myocutaneous perforators passing through the abdominal muscles.

In order to prevent the occurrence of incisional hernia, the thorough hemostasis and washing must be performed in the wound after skin flap harvesting, and then the wound is sutured close by three layers. The transverse abdominal muscle is sutured with the iliac muscle in the first layer, and then the abdominal external oblique muscle and its aponeurosis are sutured with the tensor fascia lata tendon and gluteus medius tendon in the second layer; finally, the skin and subcutaneous tissue are sutured after the negative pressure drainage is placed. For a period of time after surgery, it is required that the pillows are padded under hip and popliteal space at the side of bone donor site, and the flexed positions of the ilium and the knee joint are maintained. The off-bed activities are gradually resumed 5–6 days later.

2.1.4 Typical Case

Case I The patient, male, 51 years old, had clinical diagnosis which is right lower gingival carcinoma, $T_3N_1M_0$. The patient underwent radical resection of right lower gingival carcinoma under the general anesthesia, the primary focus in right mandible was treated with the segmental osteotomy, and the mandibular defect was repaired and reconstructed with the iliac osseo-myocutaneous flap (Fig. 9.1).

2.1.5 Common Complications and Its Prevention

The ilium is taken as the bone donor site for mandibular defect, which has a history of more than 30 years. Because its bone quantity is large and the morphology of the iliac crest is similar to that of the lower margin of mandible, the repair of unilateral mandibular defect can achieve satisfactory appearance effect and also is conducive to intraoperative or postoperative implanting to restore the chewing function after surgery. But it also has some complications in the donor site; according to statistics, after harvesting the flap, the incidence rate of abdominal external hernia is approximately 9.7%, the incidence rate of local long-term pain and discomfort is 8.4% [13, 24], and furthermore, there exists peripheral nerve degeneration and postoperative limp. In addition, the iliohypogastric nerve and ilioinguinal nerve distributed in the surgical area pass through the three layers of abdominal muscle, and their damages often occur, which causes skin numbness in the corresponding area. Therefore, the abovementioned factors must be taken into account during the operation to avoid damages of related nerves, the wound in donor site after harvesting the flap should be sutured well, and the patient is immobilized within a period of time after surgery and avoids load bearing at an early period. The local area is treated with appropriate physiotherapy to promote recovery.

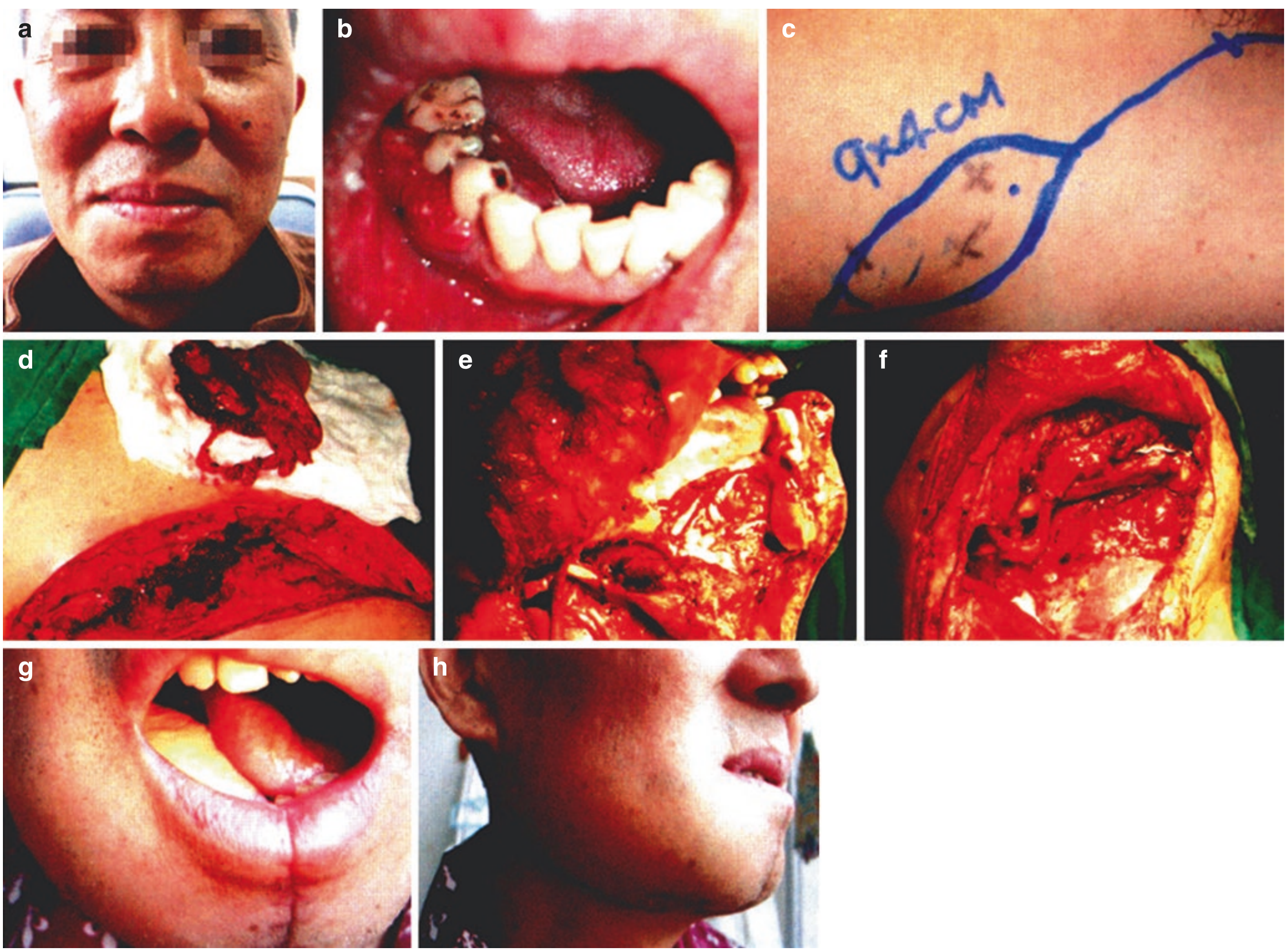

Fig. 9.1 Case I. (**a**) Positive profile before surgery. (**b**) Primary focus before surgery. (**c**) Incision design of iliac osseo-myocutaneous flap. (**d**) Intraoperative preparation of iliac osseo-myocutaneous flap. (**e**) Intraoperative resection of the primary focus. (**f**) Placement and fixation of iliac osseo-myocutaneous flap. (**g**) The flap survived well at 10 days after surgery. (**h**) Lateral profile at 10 days after surgery

2.2 Application of Fibular Myocutaneous Flap in Mandibular Reconstruction

2.2.1 Applied Anatomy

The fibula is located at the lateral side of the calf, and it is not the important load-bearing bone of the calf. Its lower one fourth participates in the composition of the ankle joint and plays a role in strengthening joint stability. The average length of fibula is about 34 cm, the upper end of fibula is expanded into the fibular head and is not directly involved in the composition of the knee joint, and it can be used in condylar reconstruction in clinics. The maximum length of fibula available for harvesting is 26 cm. The fibula has dual bone cortexes, the upper segment of its cross section is quadrilateral, the lower segment is triangular, and the appearance is constant. The average diameter of the middle segment of the fibula in Chinese people is 12.8 ± 2.4 mm in males and 11.1 ± 2.0 mm in females, respectively, which can meet the need of the implant retention. The bicortical structure can also enhance the stability of the implant.

The blood supply of the fibular osteocutaneous flap comes from the peroneal artery and its two accompanying veins. Under normal circumstances, the popliteal artery is bifurcated into the anterior tibial artery and the posterior tibial artery, and the posterior tibial artery gives off the peroneal artery; the peroneal artery and its accompanying veins run down between the flexor pollicis longus and posterior tibial muscle at the medial side of the calf. However, the blood supply of the fibula sometimes has some anatomical variations according to researches by scholars at home and abroad. Understanding these anatomical variations helps to avoid ischemic complications in feet.

The study of Wu Yongmu et al. on 100 Chinese peoples showed that the peroneal arteries are divided into four types according to different starting points: type I is given off from posterior tibial artery, accounting for 90%; types II and III are given off separately from the anterior tibial artery and the popliteal artery, each accounting for 1%; and type IV peroneal artery is absent and is replaced by the posterior tibial artery, accounting for about 8%. If the blood vessels are blindly ligated, the blood supply disorder of posterior calf muscle group may occur; at the same time, if the diameter of the anterior tibial artery is small, a phenomenon such as foot ischemia may occur. The blood supply of the fibula is characterized by the dual blood supply system of periosteum and bone marrow; namely, the fibular nutrient artery and the arcuate artery reach the bone marrow cavity, periosteum, and bone cortex of the fibula, respectively. In most cases, there is only one fibular nutrient artery; it passes through the nutrient foramen at the medial side of the fibula to enter into the bone marrow cavity to constitute the blood supply of the fibular bone marrow, providing nutrition to the bone marrow and a part of the bone cortex. There are 4–15 arcuate arteries, which are segmentally distributed along the fibula and clinging to the periosteal surface and constitute the periosteal artery network, and they are the sources of blood supply to adjacent periosteums and muscles. Even if the single source of blood supply such as the periosteum branch of the arcuate artery is retained, the fibula still can survive. This is also the anatomical basis for that multiple segmental wedge resections of the fibula flap which can be performed in clinics, and each bone segment still has sufficient blood supply.

In addition to the nutrient artery of the fibula and the muscle – periosteum vessels, it is observed that the peroneal artery and its veins also include the fasciocutaneous perforator traveling within the intermuscular space at the posterior side of calf to feed the skin in this region. Wherein, there are three thick and constant cutaneous branches at 9–20 cm below the fibular head, and the outer diameter is about 1.6 mm, which is the anatomical basis for clinical preparation of fibular flap. The in-depth studies of many scholars prove that the lateral calf skin is fed by the intermuscular space perforators of the peroneal artery; these perforators are divided into the following three types: type A, the intramuscular perforator, passes through the long peroneal muscle to reach the lateral calf skin, with no muscle branches, and is located mostly in the proximal and middle one third of the thigh; type B is also an intramuscular perforator, passes through the gastrocnemius muscle and long peroneal muscle, and gives off muscle branches before reaching the skin; and for type C, its running direction is similar to that of the type B, but it gives off the space perforator instead of the intramuscular perforator, which is mostly located in the middle and distal one third of the calf.

The study of Beppu on the distribution of blood vessel perforators in lateral calf skins of 23 patients showed that a perforator was located very constantly in the midpoint of connecting line between the fibular head and the lateral malleolus. Among the 23 patients, it was found that a perforator was located at a site within 2 cm near the midpoint in 21 patients and the blood supply provided by the peroneal artery to the proximal one third of the lateral calf skin was not constant. In the anatomies of 23 patients, the peroneal artery had no perforator supplying blood to the proximal one third of the lateral calf skin in 5 patients. While in the anatomies of 23 patients, there was at least one skin separating perforator at the middle one third of the calf. But the anatomical studies of some authors suggested that about 20% of the samples did not support the existence of the skin separating perforator and 6–25% of the samples had no muscle and muscle separating blood vessels at the same time. Therefore, it is now considered that the absolute confidence level of fibular flap is 93–94%. Although the reliability of the blood supply to the skin island is still controversial, according to Wei's report, in which the fibular flap was used in the reconstruction of 80 cases of limbs and 27 cases of mandible, the skin island had achieved a 100% successful survival rate. The author designed the center of the island design at the junction of middle one third and distal one third of the fibula and emphasized that the intermuscular space at the posterior side of calf must be included in the skin island; the operator should not pull too much in the process of flap preparation and wound closure, so as not to damage the blood supply of the skin island. Currently, most scholars adopt the method of Fleming for preparing the skin island of fibular flap, and that is to dissect at the level under the fascia from anterior to posterior. In order to be able to adapt to and accommodate possible variation in the position of intermuscular space perforators, a longer skin island can be designed. If there is no existence of the skin separating perforator, it is required to look for the myocutaneous perforator supplying blood to the skin. If there is no myocutaneous perforator given off from the peroneal artery, it indicates a need to select another separate soft tissue flap to repair the soft tissue defects. In the patients with skin separating perforators, part of muscular sleeves of flexor hallucis longus muscle and soleus muscle should also be carried, because when converging into the peroneal artery, these perforators may pass through these muscles, but the sizes of the harvested muscle sleeves should be appropriate.

The results of the study on injecting dye into the peroneal artery indicate that the average width of stained skin area is 9.9 cm and the length is 21.4 cm. Fleming successfully divided the skin island into two parts through incising the skin instead of incising the fascia.

The sensation in lateral calf skin comes from the lateral sural cutaneous nerve, which comes from the common peroneal nerve, while the common peroneal nerve is divided into the deep peroneal nerve and the superficial peroneal nerve at the fibular neck, which control, respectively, the anterior muscle group and lateral muscle group in the calf. The common peroneal nerve gives off a pair of cutaneous nerves at the outer side of the popliteal space, namely, lateral sural cutaneous nerve and the sural communicating nerve; the lateral sural cutaneous nerve controls the lateral and posterior skins in the calf. But some scholars have reported that the large lateral sural cutaneous nerve has a great variation; 22% of people lack this nerve. The sural communicating nerve is the second sensory nerve crossing the area of fibular flap, and it combines with the medial sural cutaneous nerve into the sural nerve. In clinic, according to this dissection method, the lateral sural cutaneous nerve or sural nerve is anastomosed with the lingual nerve or inferior alveolar nerve, which may restore sensory function.

There are three types of anatomical variations:

1. Fibula variation: The fibula may be absent or replaced by the ligament due to significant changes in size, which is often accompanied by abnormal tibia.
2. Blood vessel variation: The studies of scholars at home and abroad show that there is no phenomenon of the absence of the peroneal artery, and there are also no reports of the absence of anterior tibial artery. But the diameter of anterior tibial artery may be significantly reduced. Under the circumstances, only a traffic branch from the peroneal artery can provide blood supply to distal limbs with narrowed or missed arteries; therefore, the ligation of the peroneal artery may lead to ischemia in the foot.
3. Nerve variation: The lateral sural cutaneous nerve and the communicating branch of peroneal nerve have great variations, and multiple scholars have reported that these two kinds of nerves are absent in a considerable proportion of people.

2.2.2 Design Principles

The harvested fibular myocutaneous flap needs to be fixed with the reconstruction plate or the titanium plate, the fibula can be fixed only at the outer side of the fibula. And because the vascular pedicle of fibular flap is relatively short, the location needs to be designed near the mandibular angle as much as possible. Therefore, under normal circumstances, the repair of the unilateral mandibular body requires taking the contralateral calf as the donor site; the calf at the side with more defects will be selected as the donor site for repair of the anterior mandibular defect; the calf at the side of the cervical blood supplying vessels will be selected as the donor site for repair of the bilateral defects. The positioning can meet the requirement that the strong internal fixation is performed in lateral side, and the implanted implant in the upper margin does not damage the blood vessels.

Due to the limitation of the anatomical structure, the vascular pedicle of the fibular myocutaneous flap is generally shorter. The more distal osseo-myocutaneous flap will be harvested in clinics. Meanwhile, the mesial parts of periosteum and the vascular pedicle are stripped off downward, and the proximal middle bone segment is removed, so that the vascular pedicle may be extended. Hidalgo et al. [3] reported that a vascular pedicle of approximately 13 cm long can be obtained using this method. In addition, there is no significant difference in diameter between the proximal and distal ends of the peroneal artery and vein, so that the fibular flap can be used as a bridge flap. To repair a greater range of soft tissue defects, the tandem skin flap is formed when a free soft tissue flap is connected at the distal ends of the peroneal artery and vein on the fibular flap.

In order to meet the requirements for denture repair or requirements for implantation of bone fusion implant after surgery, the scholars at home and abroad increase the height of alveolar crest with the method of placement and fixation of double layers of fibula, so that the requirements for facial appearance and function after repair can be satisfactorily met. In addition, in China, Zhang Chenping applied the distraction osteogenesis techniques in stretching of the fibular flap, designed the vertical distraction of fibula built-in dental implant combining two technical advantages such as implantation and distraction osteogenesis, achieved the purpose of increasing the height of alveolar crest, and obtained ideal results.

If it is needed to prepare the fibular myocutaneous flap with sensory nerve, the osseo-myocutaneous flap with sural nerve can also be prepared, and the traffic branch of the nerve can be anastomosed with the inferior alveolar nerve to restore the sensation of fibular myocutaneous flap.

2.2.3 Preparation of the Fibular Myocutaneous Flap

According to the anatomical characteristics of the lateral calf, the corresponding anatomical landmarks are marked on its outer side. The landmark points of the muscular clearance are the fibular head in the upper part of the calf and lateral malleolus in the lower part of the calf, and the connecting line between two points is the position of the intermuscular space at the posterior part of the calf. If the skin island is needed simultaneously, it can be designed as spindle shaped, and its midline is the position of the intermuscular space. Since the main perforator of the skin flap is usually located in a slightly remote location of the calf, the central point of the skin flap is typically designed at the junction of middle and distal one thirds of the calf.

After the landmark points are drawn, that is, the dissection is started after the 350 mmHg balloon or tourniquet is wrapped around the thigh (the time of usage of tourniquet is controlled within 1–1.5 h). According to the designed incision line, incise the skin and subcutaneous tissue and the fascia on the superficial surface of the long and short fibular muscles; after that, dissect at the deep surface of this fascia from anterior to posterior and toward the direction of intermuscular space; at the moment, it is easy to find the myocutaneous perforator given off from the area near the inferior margin of fibula; the position of the skin island can be redefined according to the position of the flap perforator. After that, sharply dissect along the superficial surface of the outer periosteum of fibula, and turn up the long fibular muscle, short fibular muscle, and extensor hallucis longus; the osteotomy is performed, respectively, at the proximal middle and distal middle part of the fibula, the interosseous membrane is further dissected and exposed along the medial surface of the fibula, and the distal portions of the peroneal artery and vein are dissected out through pulling the fibula and then are ligated and cut off. Afterward, the posterior margin of the skin flap is incised at the surface of the gastrocnemius muscle and the soleus muscle to reach to the deep surface of the fascia, and the dissection is performed along this surface, and the skin island with myocutaneous perforator can be formed. This skin island can be temporarily fixed on the fibular bone flap with a needle for fear that the perforator is pulled to affect the survival of the skin island. Then the bone flap is pulled outward, and the interlaced posterior tibial muscle fibers are incised along the inner side of the peroneal artery and vein toward the direction of the proximal middle part, while the branches of the peroneal artery and vein between and within the muscle fibers are ligated and cut off to the bifurcation site of peroneal artery and the posterior tibial artery. The flexor hallucis longus must be cut off in this process, only part of the muscle sleeve is retained on the fibula, the vascular pedicle is cut off, and the fibular myocutaneous flap with a peroneal artery and two accompanying veins is formed. Because of the need to protect the vascular pedicle, the tissue flap carries part flexor hallucis longus and tibialis posterior muscle sleeves.

In the preparation of fibular bone flap, in order to avoid damage to the peroneal nerve and maintain the stability of the ankle joint, about 7 cm long bone segments must be retained, respectively, at the proximal and distal ends of the fibula. Attention must be paid to protecting the deep peroneal nerve passing through the neighboring area.

If it is needed to prepare the fibular myocutaneous flap with sensory nerve, the lateral sural cutaneous nerve given off by the common peroneal nerve must be tracked toward the mesial direction before the posterior margin of the skin flap is incised. After this nerve is found, the skin island can be reached along the nerve. The sural communicating branch can be given off at this site from the common peroneal nerve, but this nerve does not control the sensory function of this skin island and can be included into the skin island for vascularized nerve transplantation [2, 13].

2.2.4 Fibular Shaping and Vascular Anastomosis

1. Fibular shaping: In order to match the morphology of the mandible, the fibula must be shaped through closing wedge osteotomy in its lateral side; the fibula after shaping can mimic the morphology of the mandible more accurately; if the periosteum is not damaged, the multiple fibular osteotomies still will not affect its distal blood circulation. The studies of Jones et al. showed that the fibula after osteotomy may be folded to form double tubular vascularized graft and the blood supply of the distal fibula can be preserved through the intact periosteum. Sodare and Powell made improvements to the technology. They removed the middle bone segment under the periosteum, so that the remaining mesial and distal bone segments can be rotated and placed in two different three-dimensional spaces, and the fibula after shaping can undergo rigid internal fixation

with the titanium plate or reconstruction titanium plate. The accuracy of shaping is often ensured with the help of the surgical resection specimens or intraoperative prefabricated titanium plate or template. The arteriovenous preparation in the receptor site must be completed before the vascular pedicle of the fibular myocutaneous flap is cut off. The facial artery is usually selected as the artery of the receptor site, and the superior thyroid artery is selectively used in few cases. The branches of internal jugular vein or the external jugular vein are usually selected as the veins of the receptor site; if the length of the vein is not enough, the method of venous bypass can be selectively used to extend the vein in the receptor site. Under normal circumstances, two veins are anastomosed as far as possible; if the condition is not allowed, only a vein of larger diameter can be anastomosed.

2. Vascular anastomosis: Domestic and foreign scholars have different views on the sequencing of shaping and vascular anastomosis [14, 15]; at present, there are basically three types of sequencing, and these are as follows:
   (1) Shaping – cutting off the pedicle – anastomosis: The advantage of this method is that the ischemia time of the bone flap is short and there is sufficient time for vascular anastomosis, and the disadvantage is that there is no reference to the adjacent upper and lower jaw bones and the shaping operation is more difficult.
   (2) Cutting off the pedicle – shaping – anastomosis: The advantage of this method is that the shaping is mostly convenient and the method is conducive to operations such as shaping and placement; the disadvantage is that the ischemia time of the bone flap is long and the technical requirements for shaping and vascular anastomosis are higher.
   (3) Cutting off the pedicle – anastomosis – shaping: The advantage of this method is that the ischemia time of the bone flap is short, and the disadvantage is that the vascularized pedicle after shaping will have a certain limitation on shaping.

At present, most domestic scholars adopt the latter two methods; now the selection can also be based on the habits, experiences, and skill levels of the surgeons.

3. Typical Cases

Case II The patients, male, 58 years old, visited the hospital where the author was working due to having mandibular mass for 10 years; the clinical diagnosis was mandibular ameloblastoma. The preoperative examinations were performed, the preoperative CT data were input into CAD system, the mandibular model after rehabilitation was designed and produced, and the forming plate was bent on this model.

The subtotal resection of the mandible was performed under the general anesthesia, and the resection range of the mandible was from the whole left mandible to the lower right area. The mandibular defects were repaired and reconstructed with fibular myocutaneous flap. The reexamination was performed at a month after surgery, and the facial appearance of the patient was satisfactory (Fig. 9.2).

2.2.5 Treatment of Donor Site

Treatment of skin flap donor site in calf is related to the width of skin island. If the width of the skin island of the fibular flap is less than 4–6 cm, the wound in donor site can be directly closed and sutured. But the far closer to the distal middle part the position of skin island is, the greater the difficulty of suture closure is. For the skin defect with a larger donor site, the split-thickness skin graft should be transplanted to close the wound. The surgical cavity should be built in a negative pressure drainage tube before suturing the skin, and the light compression bandage is performed after suture closure. The affected limb is lifted to alleviate the foot edema at the side of skin flap donor site.

2.2.6 Common Complications and Their Prevention

1. Foot ischemia and necrosis: They are mainly due to lack of collateral circulation in the foot, which leads to the phenomenon that the foot ischemia occurs after occlusion of the peroneal artery. Detailed preoperative examination and evaluation are conducive to avoiding this danger. Most scholars advocate that detailed preoperative examination on bilateral calves is performed to determine whether there are anatomical variations caused by various factors and the preoperative angiography of the calves is important for determining whether there are anatomical variations in the peroneal artery and vein. Some scholars also believe that it is not necessary to list the preoperative angiography as a routine examination. If the pulsations of posterior tibial artery and dorsal pedal artery pulse are normal and there is no injury in the calf, it is only needed to perform an examination of color Doppler flowmetry to understand the status of the blood supply of the peroneal artery and the situation of peroneal artery perforator in lateral calf skin. If the intraoperative findings show that the peroneal artery takes the place of the posterior tibial artery, the surgeon should try to block the peroneal artery and can continue the operation after confirming the normal blood circulation in the foot toes. In addition, the preoperative MR angiography in the calf can provide the same anatomical information as the angiography.
2. Common peroneal nerve injury: The incorrect dissection or excessive pulling can cause the common peroneal nerve injury, and this leads to varus foot deformity and the numbness in the front and lateral sides of the calf and

Fig. 9.2 Case II. (**a**) Preoperative CT image. (**b**) Preoperative positive profile. (**c**) Preoperative lateral profile. (**d**) Preoperative rehabilitation model made by CAD. (**e**) Intraoperative preparation of fibular myocutaneous flap. (**f**) Fibular shaping and fixation during surgery. (**g**) Positive profile at 1 month after surgery. (**h**) Panoramic radiograph of the mandible at 1 month after surgery

in the dorsum of the foot in patients. To carefully locate and expose the nerve during surgery can avoid such a situation, and the extreme familiarity with the anatomy of the calf and the fine operation are the keys to avoid complications.

3. The bone compartment syndrome of the calf: It is required to avoid excessive tension when suturing the skin in the donor site, the wound can be closed at one stage by skin transplantation, or the dilator can also be embedded in the calf, and then the wound is closed at the second stage.
4. Other negative phenomena and dysfunctions: For example, the cold intolerance and edema and weakened bending capability in the back side of the great toe are related to the injury of the branches of the peroneal nerve or the scar contraction of the muscle, especially flexor hallucis longus. Some patients have the phenomenon of pain and weakness when walking within a few months after surgery. The muscle weakness is considered to be due to the muscles being attached to the fibula, and the interosseous membranes are stripped off and thus lose the attachment points. The detailed gait analysis shows that the patients have abnormal changes in pace, joint angle, and ground reaction force, which are related to the muscle weakness and the change in load transmission.

2.3 Application of Scapular Flap in the Mandibular Reconstruction

The history of the scapular flap applied in repair of the head and neck defects is relatively short. It began in the 1980s, but since this area can provide the skin flap, muscle flap, and bone flap simultaneously, the tissue flap in the scapular region has a repairing ability. In the head and face, it is especially suitable for repair and reconstruction of compound tissue defects involving the mandibular body, the tongue, the mouth floor, and the face, neck, and skin; namely, it is mainly used in repair and reconstruction of compound tissue defects with less bone defect which require a large volume of soft tissue. But the analysis of the application situation at home and abroad shows that it is mainly used in repair of mandibular ramus defects with more soft tissue defects among the aspects of the mandibular repair; therefore, for most mandibular reconstruction, the scapular flap is not the first method of choice.

2.3.1 Applied Anatomy

The scapula is an irregular triangular flat bone, including two surfaces, three margins, and three angles. The ventral surface or the costal surface is opposite to the upper posterior chest wall, and it is a large shallow fossa and is called the subscapularis fossa; there is a horizontal ridge at its dorsal side, which is known as the mesoscapula. The outwardly extending projection is called the shoulder peak, and the juncture of the upper margin and the vertebral margin is called the superior angle, which is at the same level of the second rib; the inferior angle is at the juncture of the vertebral margin and the axillary margin, which is at the same level of the seventh rib or the seventh intercostal space; the lateral angle is at the juncture of the axillary margin and the upper margin. The upper margin is short and thin; the medial margin is thin and sharp and is also known as the vertebral margin; the lateral margin is hypertrophical and close to the armpit and is also known as the axillary margin. Since the axillary margin of the scapula is more hypertrophical, the bone volume available for donation is larger, and the axillary margin of the scapula is usually selected as the bone donor site for repair of mandibular defects.

The blood of the scapula is mainly provided by the circumflex scapular artery (CSA), namely, the branch of the subscapularis artery (SA). SA is given off from the third segment of the axillary artery. After being given off, it runs downward for 2–4 cm and is divided into CSA and the thoracodorsal artery (TA). TA is the feeding artery of latissimus dorsi myocutaneous flap. CSA is the feeding artery of the scapula and its attached muscles and skin. CSA passes through the trilateral foramen and then bypasses along the axillary margin of the scapula and is divided into two branches such as the deep and superficial branches, namely, the cutaneous branch and the bone branch. The deep branch (bone branch) enters into the deep layers of the shoulder-back to feed the scapula, supraspinatus muscle, infraspinatus muscle, and the teres major and minor muscles; the superficial branch (cutaneous branch) is divided into the horizontal branch and the descending branch to control the scapular skin. The length of the trunk of circumflex scapular artery from the bone margin to the subscapular artery is 4–6 cm, and the outer diameter of the starting point is 2–3 mm. There are two circumflex scapular veins, which are accompanied with the artery with the same name, with a larger diameter compared with the artery. The bone tissue in the inferior angle of the scapula is generally provided with nutrition by the branch of the thoracodorsal artery – the angular branch artery – and it can be used and combined with the latissimus dorsi myocutaneous flap.

2.3.2 Design Principles

The characteristics of distribution of the vascular system in the scapular area determine that the area can either be taken as a separate donor site of the scapular bone flap or be prepared as scapular bone flap which is used in combination with scapular skin flap, dorsal latissimus flap, and serratus anterior flap. If the scapular bone flap is used alone, the bone flap at the lateral margin of the scapula pedicled with circumflex scapular artery can be used. The length and width can reach 10–14 cm × 2–3 cm, and it is used for the repair of mandibular body defect. Scapular spine bone flap supplied with blood by the thoracodorsal artery can be used to repair the defects in the mandibular angle and ramus. But in general, the scapular bone flap is rarely used alone in clinics for repair of the mandibular defect, and the composite tissue flap is still used for repair in most cases. Depending on the defect statuses in the mandible and perimandibular soft tissue, the sizes and volumes of soft tissue flaps are assessed to determine which kind of soft tissue flap is to be used. Clinically, in most cases, the composite tissue flap pedicled with SA is mostly used. If the scapular skin flap combined with scapular bone flap is selected, CSA can be taken as the vascular pedicle; if the latissimus dorsi myocutaneous flap or serratus anterior myocutaneous flap is combined with scapular spine bone flap, TA can be taken as the vascular pedicle. When the skin flap is designed, it should be taken into account whether the donor site can be closed and sutured directly, and it is supposed to avoid the skin transplantation for closing the wound in the donor site as far as possible.

2.3.3 Preparation of Scapular Myocutaneous Flap

When the skin flap is prepared, the patient should take the lateral position with donor site in the upper site. The surgeons should be very familiar with the anatomy of this region. The medial margin, lateral margin, and inferior angle and mesoscapula must be marked out before skin flap harvesting. In addition, the teres minor muscle and teres major muscle must also be marked. The space enclosed by the teres minor muscle, teres major muscle, and the long head of triceps muscle is the trilateral foramen, and this is the place where the CSA is given off. The ultrasonic Doppler can also be used to detect the trilateral foramen and the running direction of CSA. If the scapular skin flap is taken as the skin flap of the composite flap, the skin flap should be designed to take the horizontal branch of the superficial branches of CSA as the long axis and is parallel to the mesoscapula. In addition, the lateral side of the skin flap can reach the trilateral foramen; the medial site can reach the midline of the back; the upper boundary can reach the mesoscapula; the lower boundary can reach the inferior angle of the scapula. If the parascapular skin flap is taken as the skin flap of the composite flap, the descending branch of CSA should be taken as the long axis of the skin flap. The upper boundary is the trilateral foramen, and the lower boundary reaches the inferior angle of the scapula. The skin flap should be designed as spindle shaped, in order to be closed and sutured directly.

1. Surgical method: Incise the medial margin of the skin flap at first to reach the superficial surface of the muscular fasciae of the infraspinatus muscle, and separate outward along the level and turn over the skin flap. After reaching the outer margin of the scapula, locate the trilateral foramen enclosed by the teres minor muscle (the surface is covered by the luminous fascia), the teres major muscle (more muscle fibers and covered by less fascia), and the long head of triceps muscle, and pull open the teres major and minor muscles and then palpate the pulse of CSA in the adipose connective tissue of the trilateral foramen. Expose and separate the CSA and its accompanying veins; identify the muscular branch and the periosteal branch given off by CSA; ligate and cut off the muscular branch; protect the periosteal branch; separate downward the teres major muscle; expose the vascular pedicle; retain 2–3 cm of myocardial sleeve at the lateral margin of the scapula; cut off the muscles attached to the lateral margin of the scapula. At the moment, it is much more easily to expose the subscapular vascular pedicle. If the bone flap in the inferior angle of scapula is not needed, the thoracodorsal artery should be ligated; if the thoracodorsal artery is needed, it will be required to cut off the teres major muscle and dissect out the subscapular vascular pedicle at the deep surface of this muscle. This branch can be given off either by the thoracodorsal artery or by the vessel from the thoracodorsal artery which enters into the serratus anterior muscle.

After separation of the skin flap and the vascular pedicle flap, incise the teres minor muscle and the infraspinatus muscle to reach the bone surface at 2–3 cm on the medial side of the lateral margin of scapula. Strip off the periosteum at the osteotomy line, incise at 2–3 cm parallel to the lateral margin with the reciprocating saw to reach the area beneath the glenoid fossa, and then perform the transverse osteotomy. At this time, be careful to protect the vascular pedicle and the structure of the shoulder joint. Meanwhile, to ensure the blood supply, the reverse side and the ventral side of bone flap should be retained with a thin layer of muscle fibers, after dissociation of the bone flap, and the artery and vein can be ligated and cut off at the start of the subscapular blood vessels to the receptor site.

2. Typical cases: This was a case of repair of mandibular defects with vascularized scapular myocutaneous flap (provided by professor Sun Jian from the Department of Oral and Maxillofacial-Head and Neck Surgical Oncology of Shanghai Jiao Tong University Affiliated Ninth People's Hospital).

Case III The patient, female, 67 years old, had tumor recurrence and invasion of right tongue body after undergoing rib transplantation within another hospital due to mandibular ameloblastoma. The patient underwent segmental resection of the mandible, resection of the right half of the tongue, and the repair with the scapular myocutaneous flap under general anesthesia in our hospital. The facial appearance of the patient at 3 weeks after surgery was satisfactory (Fig. 9.3).

2.3.4 Treatment of Donor Site

After preparation of the composite scapular myocutaneous flap, since it is required to cut off more muscle attachments during surgery, the upper arm function may be affected after surgery, which is mostly obvious in the teres major muscle. Because it is the muscle responsible for internal rotation, outreach, and adduction of the upper arm, the function will be inevitably affected after its cutting off. Therefore, a hole must be punched in the broken end of the scapula, and the severed muscle attachment is fixed onto the bone hole with nonabsorbable suture lines, so as to achieve the purpose of fixing the scapula and preventing the drift. After harvesting of the soft tissue flap, the skin defect within the range of 12–15 cm can be closed and sutured directly, and the negative pressure drainage is carried out. The shoulder is immobilized for a week after surgery, and then the activities of the shoulder are gradually recovered 1 week later. After a period of time, then the strength-training exercises of the shoulder and upper limb are gradually increased, but it is supposed to avoid violent abduction and external rotation movements.

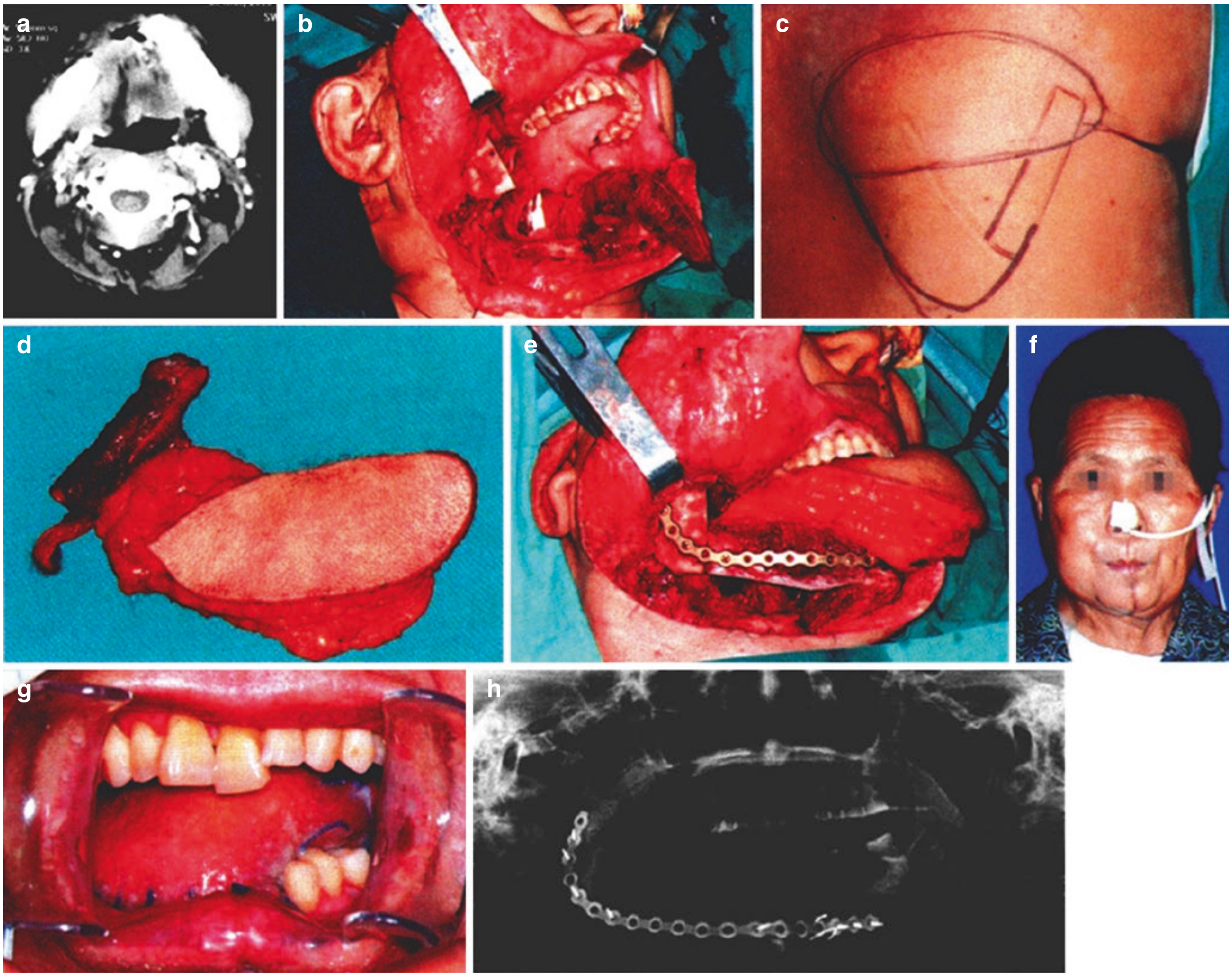

Fig. 9.3 Case III. (**a**) Preoperative CT scan showed that the tumor invaded the right tongue body. (**b**) The defect range after tumor resection. (**c**) Design of scapular myocutaneous flap. (**d**) The prepared scapular myocutaneous flap. (**e**) Reconstruction of the mandible with the scapula. (**f**) Positive profile at 3 weeks after surgery. (**g**) The intraoral image at 3 weeks after surgery. (**h**) Panoramic radiograph at 3 weeks after surgery

3 Application of Other Methods in Mandibular Reconstruction

3.1 Nonvascularized Bone Transplantation

Currently, the repair of the mandibular defect using the vascularized autologous bone transplantation has been the most commonly selected method in clinics, including the fibular myocutaneous flap with vascular anastomosis, the iliac bone flap, the scapular myocutaneous flap, and the tibial flap. In addition, in some circumstances, the nonvascularized autologous bone transplantation can be used to repair the mandibular defect in clinics; the autogenous particulate bone marrow-cancellous bone transplantation and the replantation of the autologous and freezed diseased bone have also been clinically applied. But compared to vascularized bone transplantation, the survival rate of such bone transplantation is significantly lower than that of the former, especially when applied to the wounds after radiotherapy. It is reported that, in these cases, the incidence rate of exposure, absorption, and infection of the transplanted bone is at least 58% and the incidence rate of local complications after radiotherapy can be up to 80%. While the main cause of failure is still the postoperative infections, therefore, this method is only applicable to those patients with good local blood supply, enough soft tissue covering the bone, and short defects (about 5 cm) and without a history of local radiotherapy. Because the nonvascularized bone transplantation techniques are simple and easy to spread, the surgery time is short, there are some clinical applications, and the ilium and ribs are currently more commonly used.

3.1.1 Iliac Bone Transplantation

The ileum is a donor site which is more commonly used for bone transplantation and has abundant cancellous bone, in which there are many interspaces and viable cells, which can rapidly lead to revascularization and osteogenesis, and the new trabecular bone formation can be observed on the 10th day after transplantation. The adult ilium can provide a bone block of about 10 cm × 5 cm. When the iliac bone transplantation is selected, the ipsilateral iliac crest is usually selectively used, because the radian of the ipsilateral iliac crest is basically consistent with that of the inferior border of mandible but is slightly opposite to that of the contralateral one. Meanwhile, the morphology of the anterior superior iliac spine is perfectly matched with the mandibular angle. When the mandibular defect involves the mandibular angle, the anterior superior iliac spine can be used for repair of defects in the mandibular angle.

Currently the nonvascularized iliac bone is mainly used to repair defects in the mandibular chin-body, and the repair length is generally limited within 5–8 cm. But some scholars at home and abroad choose to use it in patients with bilateral body defect crossing the midline and have also achieved good results. But be sure to pay attention to selecting the patients with good local blood supply and without soft tissue defects [24].

Precautions for the implantation and fixation of the iliac bone block: before bone transplantation, the hydrogen dioxide solution and normal saline are used to wash the wound, and the complete hemostasis is carried out. Before suturing the oral mucosa, it is noted that the heights of the bilateral broken ends of the bone are slightly reduced, so that the surrounding oral mucosa and submucosal tissue are sutured without large tension. The oral mucosa should be sutured by layers, the mucous layer is sutured at first, and then the submucous layer is sutured with 3-0 absorbable suture line. After the suture is completed, the normal saline is used again to wash the wound and the hemostasis is performed. The wounds in the broken ends of the bone and the two ends of the implanted bone block are trimmed to realize the end-to-end joint. After the titanium plate fixation is performed, the local drainage is carried out, and the layer suture is performed.

3.1.2 Rib Transplantation

For patients with defects in mandibular body and ramus or defects in most of the mandible, the rib transplantation is a better approach under the condition that the vascularized bone transplantation technology can't be used, because the rib is long enough and is easy to bend and shape, and the complications in donor site of the rib are also very rare. In general, one of seventh, eighth, and ninth ribs is taken as the bone graft. If the mandibular defect needs to be repaired, it is advisable to take the contralateral rib. Currently the rib and costal cartilage are considered to be the most suitable tissue for condylar reconstruction.

1. Harvesting method: A curved incision is made at the anterior end of the costal cartilage and backward along the costal margin, and the skin, subcutaneous tissue, and deep fascia are incised to expose the muscle layer covering the superficial surface of the ribs, which is incised and separated slightly to expose the ribs. The periosteal incision is made along the central rib at the outer side of the bone, and then a vertical incision is made at both ends. The periosteal detacher is clung to the bone surface, and each surface of the rib is stripped off carefully under the periosteum. When the periosteum is stripped off, the stripping by the detacher should be performed following the direction of the intercostal space, so as to avoid the difficulty of stripping and damage to the surrounding structure and puncturing through the pleura. At the same time, a pivot should be found out during operation as far as possible, and the stronger operations should be avoided to prevent the slipping of detacher and the pleural or lung tissue damage. After stripping off, the rib with the desired length is cut off. If the pleuron has been punched through during operation, it should be repaired with timely measures, such as transfer of adjacent muscle flap. After the donor site of the bone is washed and the hemostasis is performed, the drainage tube is placed and the layer suture is performed, and the chest compression bandage is carried out. The patients should be encouraged to cough to avoid respiratory complications.
2. Implantation and fixation of the rib: Before implantation it should be clear that the hard rib is used to repair the mandibular body and the soft rib is used to repair the mandibular ramus and the processus condyloideus. The methods for combining with the remaining mandible include two methods such as inlay type and insert type. The former is that the part of the bone cortex at the buccal side of the broken ends of the mandible is removed, which is embedded and fitted into the rib with removal of same volume of bone cortex, and then is fixed with the titanium plate or steel wire; the latter is that the end of the rib is trimmed into sharp form and then is inserted into a space in the broken end of the mandible which is prepared in advance; it is generally required that the inserting depth is at least 1 cm. After the broken end is fixed, the lingual soft tissue should be fixed onto the rib with absorbable suture line to ensure no gap exists at the lingual side of the

implanted bone, then a drainage tube is placed into the operative cavity, and the intraoral soft tissue and the lateral soft tissue are sutured, respectively.

3.2 Application of the Reconstruction Plate in Repair of the Mandibular Defect

Since the 1980s, the immediate bridge repair of mandibular defect with the reconstruction plate has been widely used in the world. At first, this technology is a temporary repair method produced based on the consideration of the people whether the tumor recurrence is covered up due to the immediate repair after radical resection of mandibular malignant tumors and its surrounding area, which can retain the position of the residual mandible, maintain the facial appearance of the patient, and maintain some oral functions; it plays a very important role in maintaining bone shape to create conditions for second-stage bone transplantation, preventing the fracture or shift of the residual mandible and reducing the rate of tracheotomy.

But in clinical practice, the people have gradually discovered that a variety of clinical complications will appear after a period of time after the immediate bridge repair of mandibular segmental defect with the reconstruction plate, such as the loosening and falling off of the screw, the fracture of reconstruction plate, and the exposure of the reconstruction plate, which can easily lead to medical disputes. With the progress and popularization of microsurgical technique, and more emphases are put on postoperative quality of life in the current tumor treatment, therefore, the indications for the immediate bridge repair of mandibular segmental defect are controlled more strictly. Currently, this technology is mainly used in repair of mandibular segmental defect caused by malignant tumor with poor prognosis, but it is also used in patients with bad blood vessel condition or poor general condition, patients who can't tolerate the microsurgical operation, and patients with the preventive use of reconstruction plate to prevent the postoperative fractures caused by curettage treatment and marginal resection of the mandible.

3.2.1 Basic Principles of Operation

Reconstruction plates are divided into straight type, right and left single-curved type, and double-curved type, and the latter two types can be combined with artificial condyle prosthesis to be used for joint reconstruction. Generally the reconstruction is 2.0–2.5 mm in thickness, and the diameter of the retaining screw is 2.4 mm. Currently, there is a reconstruction plate of the screw head locking type. The screw locking between the screw and the plate hole is used to achieve stability between the plate and screws and prevent the friction between plate and screws and thus avoid the compression ischemia caused by the fixation achieved by pressing the reconstruction plate on the bone surface with screws and meanwhile avoid the displacement effect of the reconstruction plate without screw locking on the residual bone. The selection of the reconstruction plate is generally determined based on the location and extent of the bone defect. The reconstruction plate should be bent into shape during surgery along the external surface of the inferior margin of mandible and the posterior margin of the mandibular ramus. But the template is used for shaping on the surface of the bone at first, and then it is relatively easy to bend and make the reconstruction plate according to the template. If there is a mandibular model performed by computer-aided design/computer-aided manufacture (CAD/CAM) before surgery, the reconstruction plate can be bent into shape before surgery, which can greatly shorten the operation time, and at the same time, it is easier for the prefabricated reconstruction plate to cling to the bone surface.

In addition, if there is no lesion uplift in the outer and lower margins of the affected mandible, the reconstruction plate should be bent into shape according to the morphology of the mandible before lesion resection. After removal of the iconic lateral drill holes, at least two holes are drilled respectively on each side. The reconstruction plate is removed after the screws are fixed. In this kind of situation, it is best to use the lock screws, in order to prevent that when the screws are fixed again after osteotomy, the reconstruction plate loses its original position due to the pressurization of the screws, which leads to the displacement of bilateral bone segments.

If the osteotomy position is varied due to the tumor invasion, a reconstruction plate can be bent and made into the shape of arch and cross the osteotomy area to connect the remaining bone segments, and the positioning fixation is carried out, and then it is removed. After osteotomy, the reconstruction plate is reused to recover the position of the residual bilateral bone segments; at the same time, another reconstruction plate is used; the bridging fixation is performed along the lower margin of the residual bone segment, and then the retention reconstruction plate is removed again.

When the reconstruction plate is bent and made, it is required to avoid repeated bending and linear bending at the same site, so as to avoid creases in the reconstruction plate which leads to its premature breakage; meanwhile, it is necessary to appropriately reduce the degree of convexity of the appearance of the reconstruction plate at the areas of the chin and mandibular angle to avoid the occurrence of bedsore and ulcers caused by larger soft tissue tension and thus prevent the soft tissue from being penetrated and exposed.

When the screws are fixed, it should be ensured that the screws penetrate the contralateral bone plate and are held onto double layers of bone cortexes. Three or more screws are required for retention in the major load-bearing bone segment to spread the load stress and thus prevent screw loosening. In addition, after the reconstruction plates are fixed, the appropriate suspension of the muscles in the floor of the mouth must be performed to recover the original position of the muscle group in the floor of the mouth and avoid shortness of breath caused by the soft tissue recession.

3.2.2 Soft Tissue Repair

The resection of soft tissue malignant tumor in mandible and its surrounding area inevitably causes the soft tissue defects, and the reconstruction plate requires tension-free suture and coverage; therefore, it must be considered simultaneously to carry out the repair and reconstruction of soft tissue defects. We usually use the pectoralis major myocutaneous flap or the free anterolateral femoral skin flap to repair the soft tissue defects and cover the reconstruction plate.

3.2.3 Common Complications and Their Related Factors

Postoperative complications include postoperative infection, soft tissue ulceration, the fracture of reconstruction plate, and screw loosening, and their related factors include the following main points:

1. Radiotherapy: The postoperative radiotherapy often causes blood supply obstacles in soft tissues around the titanium plate; at the same time, symptoms such as edema and fibrosis appear in the soft tissues; and all these are the main causes for ulceration of the skin and mucous membranes. Meanwhile, the radiation damage and local blood supply obstacles may also reduce the bone regeneration. The studies have shown that the radiotherapy dose of more than 40 Gy can cause irreversible changes in bone tissue and reduce the activity of the bone tissue, so that the titanium plate after implantation cannot cause the fusion between bone and screw as scheduled, with the effect of the functional load; the bone resorption occurs gradually around the screws, ultimately leading to screw loosening and local chronic infection. Studies have shown that there are significant differences in incidence rates of titanium plate exposure and screw loosening between patients with and without radiotherapy.
2. Insufficient retention stability: There are two major causes for insufficient retention stability. On the one hand, the operation is improper. For example, the excess temperature in the process of drilling bone hole causes the osteonecrosis at the surface of the bone hole, which affects the integration of bone and screw after implantation of titanium screw, or the retaining screw is not long enough, and it is not bicortical fixation; on the other hand, there is a structural difference in retention stability between retention devices.
3. Undue stress concentration: It is needed to use the reconstruction plate to replace the defected bone segment to bear and transmit the functional load during the mandibular movement. The load force is transferred to the bone end through the fixed structure and thus generates the combined stress in the bone. The stress is mainly concentrated on the bone tissues surrounding the retaining screws. When the stress exceeds the tolerance limit of the bone, the bone resorption around the screws will occur. This will lead to the retention screw loosening. In addition, the angle area and bending section of the reconstruction plate are stress concentration sites. For example, the long-term repeated stress accumulation in the mandibular angle and chin can cause the mechanical fatigue in the sites, which will lead to the fracture of the reconstruction plate.

4 Prospect on Repair and Reconstruct of Mandibular Defects After Tumor Surgery

After nearly a hundred years of continuous efforts by experts and scholars in the countries all over the world, the repair and reconstruction of mandibular defects after tumor surgery have achieved great progresses, which can cure the disease of the patient, repair the mandibular defects, reestablish the oral functions of the patient to varying degrees, and recover the normal morphology of lower one third of the face of the patient at the same time. In recent years, a new digital simulation technique combined with CAD/CAM has been used in reconstruction of mandibular defects, for, no matter what kind of mandibular defect, the digital model can be used to simulate the ideal mandibular morphology and create a solid model. According to the defect scope, the position and angle of the osteotomy line of the bone graft can be designed through preoperative virtual surgery on computer or 3D printing technology. Meanwhile, cutting guide plate of the bone graft is designed and manufactured. So the operative process of the mandibular reconstruction can be more programmed and standardized, and the operation time would be significantly shortened. An important step has been taken in achieving the purpose of refinement and individualization in mandibular reconstruction.

But there are still some problems in the mandibular reconstruction to be solved; for example, the main transplantation materials are the vascularized autogenous bones, which lead to a new trauma in patients. Meanwhile, there still exist some problems such as varying degrees of muscle power loss along with the mandibular defects. How to solve the issue of muscle power recovery after repair of large and complex mandibular defects has been one of the research directions for scholars from various countries.

In terms of alternative materials of autologous bones, current researches focus on the aspects such as tissue-engineered bone and implantable prosthesis. The scholars from various countries have made some progresses in these areas through long-term efforts, but there are still a lot of basic researches to be made on repair of mandibular segmental defects. However, with the continuous development of science and technology, we believe that new breakthroughs will certainly appear in these areas in the near future, which will bring the Gospel to the patients.

All surgical photographs published in this chapter have been approved by the patients themselves.

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