Poor condyle position after mandibular reconstruction and a classification system for patients with "VSCU" based on computed tomography: a cross-sectional study with retrospective data collection

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Background: Although the application of vascularized free bone muscle flap to reconstruct the mandible has become a standardized approach for mandible reconstruction, the results of its reconstruction are not always satisfactory. The purpose of this study was to identify the types of mandibular and condylar defects by analyzing the unsatisfactory cases of mandibular reconstruction in clinical practice, and to provide some clinical experience of reconstruction.

Methods: Our study retrospectively analyzed 364 patients who underwent mandibular resection and vascularized free bone flap reconstruction of the mandible and temporomandibular joint (TMJ). We innovatively proposed a "VSCU" classification system (V: vertical position, S: sagittal position, C: coronal position, U: condylar resection is not required) by analyzing computed tomography (CT) scans of mandibular branches and TMJs.

Results: In all, 221 cases of free iliac muscle flap and 143 cases of fibula muscle flap were included in this study, of which 23 cases had unsatisfactory results after TMJ reconstruction. We classified 23 patients with unsatisfactory mandibular reconstruction according to the "VSCU" classification system. The most common type was U + V + SfC (n=8), followed by V – SfC + U + (n=4), V – s + C + U + (n=3), V – sbcou – (n=3), V – SBC + U + (n=2), V – s + C + U – (n=1). The most common classification was insufficient mandibular rami length, followed by condylar sagittal anteriorization. There was no significant change in the position of condyle on the healthy side during mandibular reconstruction involving condyle. P1 on the affected side was 52.28±4.17 mm before operation and 58.94±5.65 mm after operation, P<0.01; P2 was 12.83±3.49 mm before operation and 24.90±7.15 mm after operation. S2 was 4.54±2.84 mm before operation and 19.10±8.54 mm after operation. A2 was 11.46±3.35 mm before operation and 24.15±8.29 mm after operation. The P values were all less than 0.01, and the differences were statistically significant.

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Conclusions: We propose to use the "VSCU" classification system for accurate 3-dimensional (3D) analysis and positioning, and then obtain accurate models through computer-aided design and manufacturing (CAD/CAM), which can reduce the occurrence of poor reconstruction effect and unreasonable joint position, and is worthy of clinical promotion.

Keywords: Reconstruction of mandible; computer-aided design and manufacturing (CAD/CAM); temporomandibular joint (TMJ); condyle position; bone defects

Introduction

At present, the significant aesthetic and functional deformities caused by mandibular defects arising from trauma and tumor resection are a great challenge. The purpose of mandibular reconstruction should consider the restoration of maxillofacial structure and aesthetics to improve the quality of life of patients. The reconstruction of mandible with vascularized free bone myocutaneous flap has become a standardized procedure for mandibular reconstruction because it can allow a wide range of mandibular defect composite tissue reconstruction. As microsurgery advances, the success rate of vascular anastomosis has neared 100% (1,2). However, we found that there were still some unsatisfactory cases after mandibular reconstruction. Three common types of undesired reconstruction include: insufficient alveolar bone height, unsatisfactory mandible formation, and improper temporomandibular joint (TMJ) position. Improper TMJ position is the most common type in this retrospective study.

TMJ dysfunction is defined as a subgroup of craniofacial pain problems involving the TMJ, masticatory muscles, and associated head and neck musculoskeletal structures. Patients with TMJ dysfunction are most often experiencing mandibular movement pain, limited movement, and mandibular deviation. Malocclusion is considered the cause of "TMJ dysfunction" and associated facial pain (3). At present, the main purpose of mandibular reconstruction is to maintain proper occlusion and provide a structure for dental implantation, so that the toothless mandible can produce and withstand the masticatory force required for complete oral function (4,5). However, few studies on mandibular reconstruction have focused on the stability of the condyle after operation. The purpose of this study was to analyze the unsatisfactory cases of mandibular

reconstruction in clinic, to propose the classification of TMJ repair, and to provide some clinical experience.

Based on the development of virtual surgery based on computer-aided design and manufacturing (CAD/CAM) and 3-dimensional (3D) printing technology, the focus of mandibular reconstruction has been shifted to optimal function and aesthetic repair. Using a "double-fold" fibular myocutaneous flap can solve the problem of insufficient height of the mandible, and 3D printing can help reconstruct satisfactory mandibular molding (6-8). However, there have been few reports on the position of the TMJ after reconstruction. Since the proper position of the TMJ is related to the function of allowing adequate mandibular movement and chewing, it is very important to accurately reconstruct the position of the TMJ. Our experience found that the limitations of surgical techniques and the deviation of the individual experience of the surgeon can easily lead to improper TMJ position, resulting in unsatisfactory mandibular reconstruction. Therefore, the purpose of this retrospective study was to report some unsatisfactory cases of mandibular reconstruction due to improper position of TMJ, and to propose a classification system to provide some experience for later reconstruction of TMJ. We present this article in accordance with the STROBE reporting checklist (available at https://qims.amegroups.com/article/view/10.21037/qims-23-1444/rc).

Methods

Patients

This study retrospectively analyzed 364 patients who underwent mandibular lesion resection and vascularized free muscle flap reconstruction surgery at Department of Oral and Maxillofacial Surgery, the Affiliated Hospital of Qingdao University from December 2012 to November
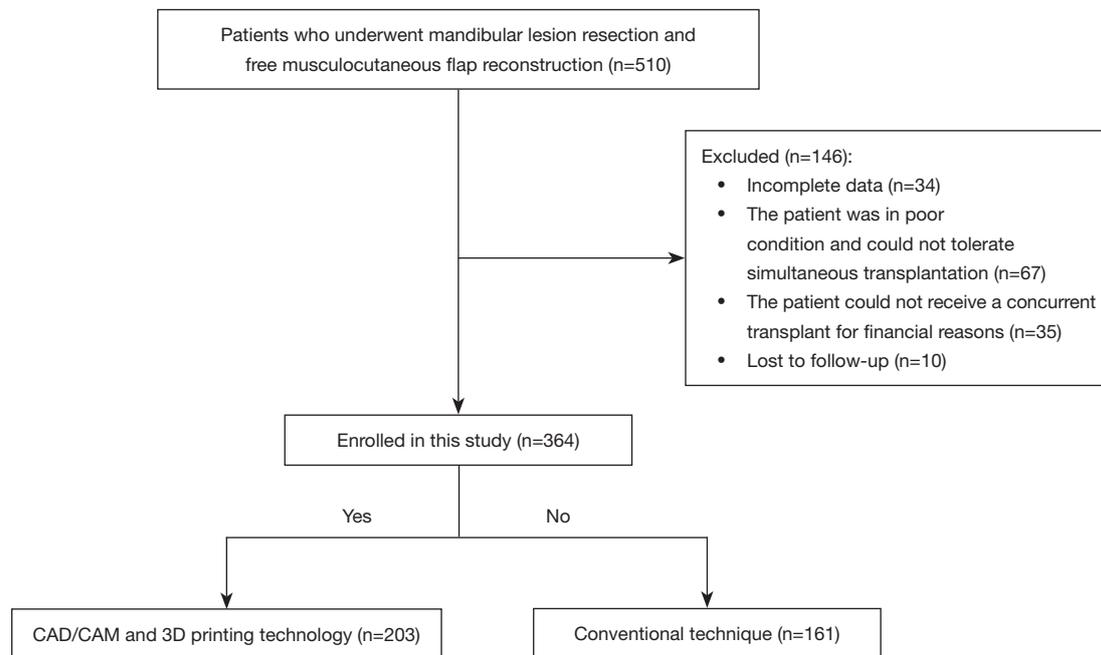
Figure 1 Patient selection flowchart. CAD/CAM, computer-aided design and manufacturing.

2019. All patients underwent mandibular computed tomography (CT) scan before operation. Age, sex, diagnosis, and perioperative details of patients were recorded. Among the cases, 218 were male and 146 were female, with a mean age of 41 years (range, 13 to 72 years). Diagnoses were squamous cell carcinoma (82 patients), ameloblastoma (124 patients), odontogenic keratocyst (22 patients), osteosarcoma (9 patients), ossifying fibroma (9 patients), and other diseases (118 patients). All cases underwent simultaneous tumor resection with mandibular reconstruction using CAD/CAM and 3D printer technique in 203 cases and a conventional technique in 161 cases (*Figure 1*). This retrospective study was conducted in accordance with the Declaration of Helsinki (as revised in 2013) and was approved by the Medical Ethics Committee of the Affiliated Hospital of Qingdao University with the Human Ethics Approval Number [(2021) IEC (099)]. The TMJ position relationship was evaluated by an independent investigator. Informed consent was provided by all the patients.

Classification of improper condyle position

The recovery of TMJ function after tumor resection depends on the accurate reconstruction of TMJ position. There are several clinical situations in which patients may not be satisfied with the results: (I) mandibular ascending branch abduction; (II) insufficient mandibular lifting height; (III) poor positioning of the condylar process relative to the articular fossa (*Figure 2*). The reconstruction of the condylar head during surgery was divided into the following cases: (I) for benign tumors of the mandible, if the lesions did not involve the condylar neck, the condylar head was retained *in situ*. (II) If benign tumors of the mandible accumulate in the condylar neck, but the condylar head is not significantly destroyed, the condylar head can be frozen in liquid nitrogen and then re-implanted into the reconstructed condylar head. (III) For mandibular malignant tumors, if the condylar neck is involved, the condylar head should be completely removed and a donor bone flap should be used to replace the mandibular condyle. (IV) For patients with insufficient bone flap length in the donor area after reconstruction, artificial joint reconstruction of condyle can be selected (*Figure 3*). In this study, the criteria for determining whether the condyle would be preserved were as follows: (I) for mandibular benign tumors, the scope of lesion resection should be 1 cm outside the tumor boundary; if the scope of lesion involved the neck of the condyle, the condyle should be removed; if the scope of the lesion is not involved in the neck of the condyle, and there is no obvious abnormality of the condyle, the condyle can be removed surgically, frozen in liquid nitrogen for
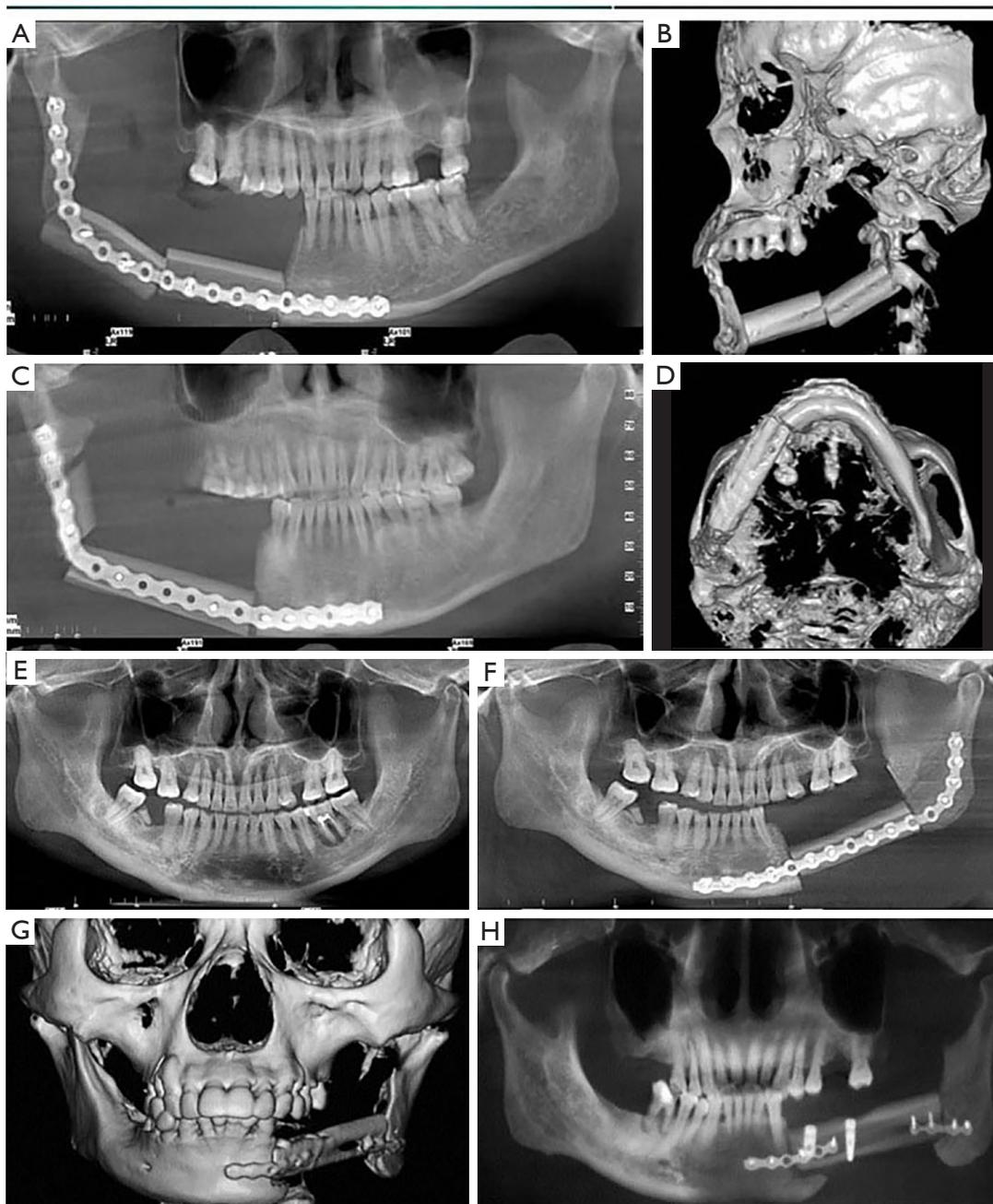
Figure 2 Clinical unsatisfactory cases of mandibular reconstruction. (A-D) Insufficient alveolar bone height after reconstruction. (E,F) The mandibular reconstruction was not ideal, and there were steps at the lower margin of the mandible. (G,H) After reconstruction, the ascending branches of the mandible are extended, the temporomandibular joint is not in an appropriate position, and the mandible morphology and alveolar bone height are not ideal.
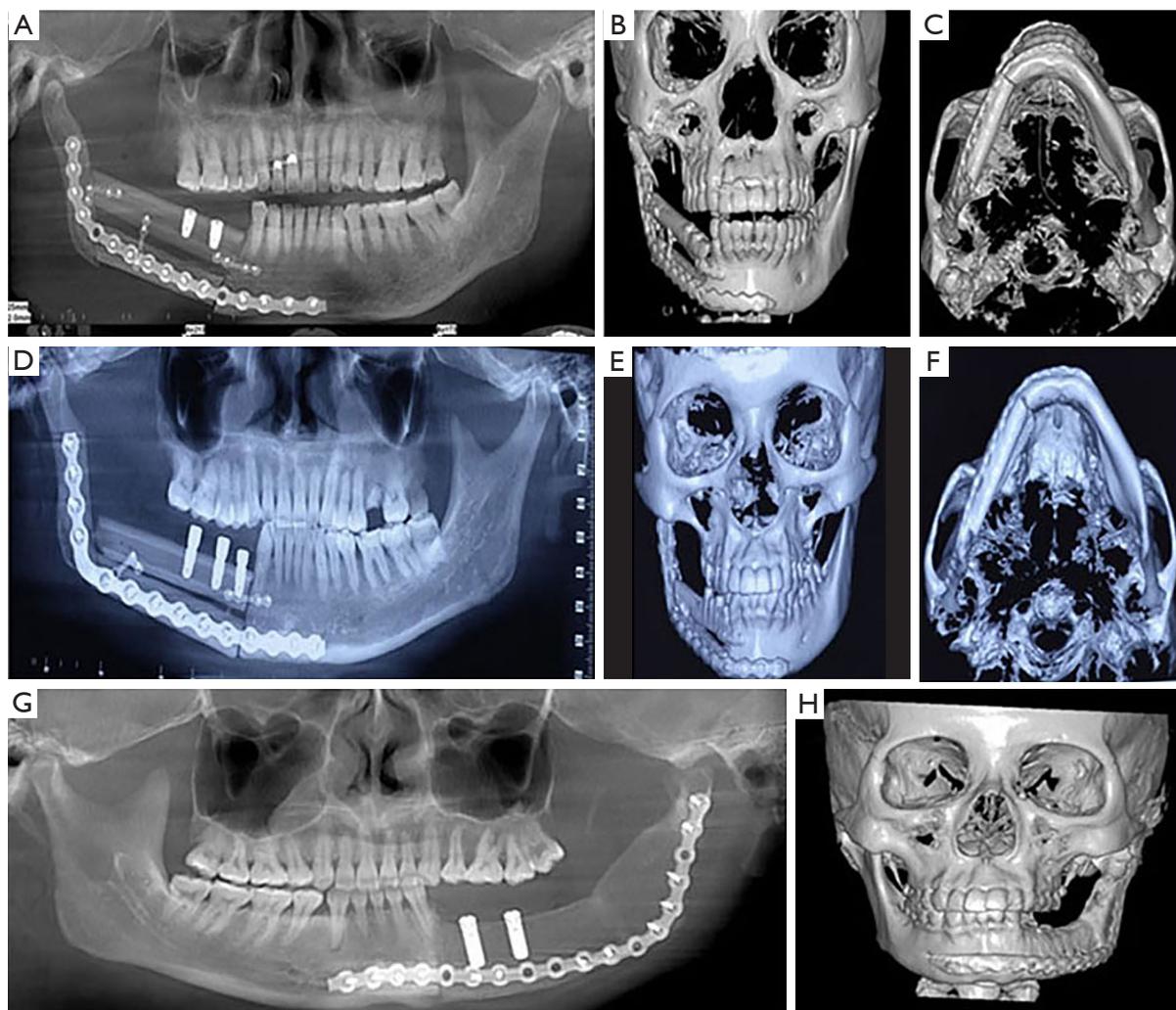
Figure 3 Poor temporomandibular joint position after reconstruction. (A-C) The mandibular ascending branch height is insufficient after reconstruction, resulting in poor temporomandibular joint position. As shown in (D-F), the mandibular ascending branch height is too long, resulting in the condylar process against the articular disc, affecting the mandibular movement and causing pain. (G,H) Mandibular abduction after reconstruction, with the temporomandibular joint positioned in front of the joint tubercle.

3 times, then implanted into the articular fossa, and fixed with titanium plates and reconstructed bone ends. (II) For mandibular malignant tumors, the scope of lesion resection should be 2–3 cm outside the tumor boundary. At this time, if the condyle or the neck of the condyle is involved, the condyle should be removed during surgery. Thus, resection of the condyle is seldom necessary and the preservation of condylar head in these immature patients will avoid the long-term problems associated with growth center loss. There are now universal criteria for the classification of TMJ position. Our focus is on TMJ position after mandibular reconstruction using free fibula and iliac muscle

flap. We analyzed CT images to evaluate the morphology and pathology of the joint, mandibular rami, and condyle. Our proposed "VSCU" classification system is based on the position of the condylar head on the longitudinal (V), sagittal (S), coronal (C) axis of the TMJ and whether condylotomy was performed (U) (*Figure 4*).

❖ V (vertical position):
  ◆ V+: the length of mandibular ramus is enough to allow the condyle to stay in the mandibular fossa.
  ◆ V−: the length of mandibular ramus is not enough to allow the condyle to stay in the

VSCU classification

V (vertical position)
→ V+: the length of mandibular ramus is enough to allow the condyle to stay in the mandibular fossa
→ V−: the length of mandibular ramus is not enough to allow the condyle to stay in the mandibular fossa

S (sagittal position)
→ Sf: the condyle shifts forward on the sagittal axis
→ Sb: the condyle shifts backward on the sagittal axis
→ S+: the condyle stays at adequate position on the sagittal axis

C (coronal position)
→ Co: the condyle shifts outside on the coronal axis
→ Ci: the condyle shifts inside on the coronal axis
→ C+: the condyle stays at adequate position on the coronal axis

U (unnecessary resection of the condyle)
→ U+: necessary resection or preservation of the condyle
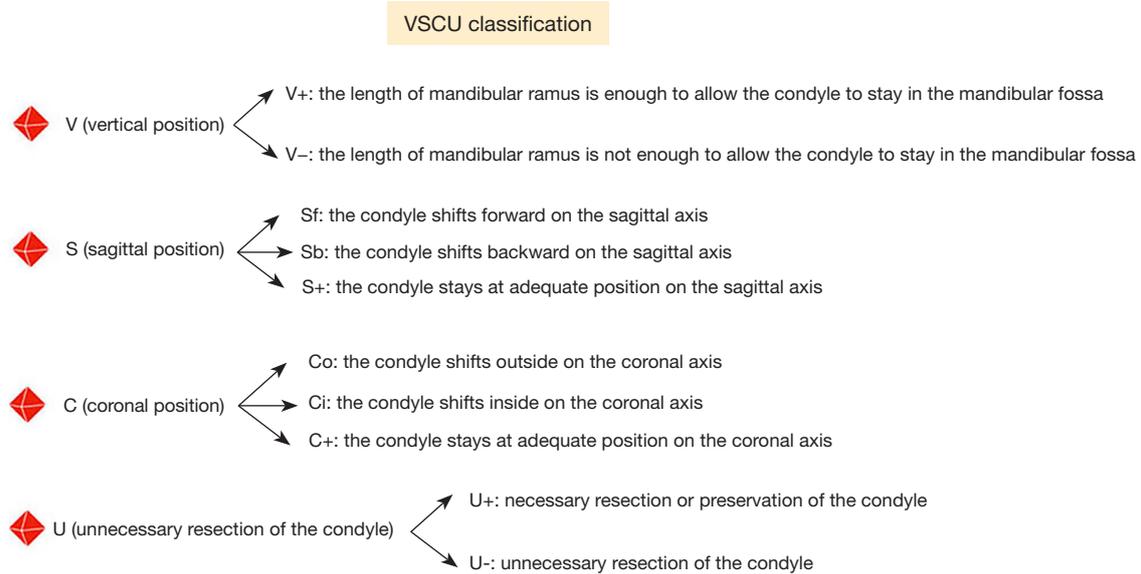→ U-: unnecessary resection of the condyle

Figure 4 VSCU classification diagram. V, vertical position; S, sagittal position; C, coronal position; U, unnecessary resection of the condyle.

mandibular fossa.

❖ S (sagittal position):
  ◆ Sf: the condyle shifts forward on the sagittal axis.
  ◆ Sb: the condyle shifts backward on the sagittal axis.
  ◆ S+: the condyle stays at adequate position on the sagittal axis.
❖ C (coronal position):
  ◆ Co: the condyle shifts outside on the coronal axis.
  ◆ Ci: the condyle shifts inside on the coronal axis.
  ◆ C+: the condyle stays at adequate position on the coronal axis.
❖ U (whether condylotomy is required):
  ◆ U+: condylotomy is required.
  ◆ U−: condylotomy is not required.

Quantitative analysis of postoperative condyle position

The nasal root point (N), anterior nasal ridge point (ANS), and sella point (S) were selected to define the sagittal plane, and the left and right infraorbital margin points (OrL, OrR) and the highest point of the left external auditory canal (PoL) were selected to define the orbital ear plane. They were located on cone-beam computed tomography (CBCT) before and after operation, CS: the uppermost point of condyle; CP: last point of condyle; CA: most anterior point of condyle; VC: vertical angle point (the intersection point between the posterior edge of the ascending branch of the mandible and the lower edge of the mandible body); HC: horizontal angular point (the point at which the long axis of a cusp meets the lower mandibular margin, usually about 7 mm from the mental foramen). The indicators and significance of mandibular fixed-point measurement are shown in *Table 1*. The landmarks in the cranial part were relatively constant, and each marker and angle had the normal reference range of cranial and maxillofacial surgery. Meanwhile, it is of great reference value and significance to compare the points and angles after surgery with those before surgery, as well as the preoperative reconstruction design. Therefore, the statistical analysis using this method as a retrospective study has very high reliability (*Figure 5*).

CAD/CAM and model measurement

The mandible was scanned using spiral CT with a thickness of 1.5–2 mm. Then, the digital information of CBCT 2-dimensional (2D) image was processed by 3D software to display a 3D reconstructed image. 3D solid modeling was performed as follows: CAD/CAM numerical control technology, fused deposition modeling (FDM) rapid prototyping technology, processed with resin to make a smooth outline, and the actual anatomical shape of the patient's bone tissue was exactly replicated by the

Table 1 Mandible fixed point measurement index and its significance

Index	Significance
MH (mm)	The length of the ascending mandibular branch, i.e., the distance from CS to VC
V-S (mm)	VC to the median sagittal plane
V-H (mm)	Mandibular length, i.e., distance from VC to HC
SMA (°)	Angle of mandibular angle, i.e., angle between CP-VC connection and VC-HC connection
CMA (°)	The angle between the ascending mandibular branch and the sagittal plane, i.e., the angle between the CS-VC line and the sagittal plane
AMA (°)	The angle between the mandibular body and the sagittal plane, i.e., the angle between the VC-HC connection and the sagittal plane
P1	Distance from posterior condylar point to sagittal plane
S1	Distance from supracondylar point to sagittal plane
A1	Distance from anterior condyle to sagittal plane
P2	Distance from posterior condylar point to orbito-auricular plane
S2	Distance from supracondylar point to orbitoauricular plane
A2	Distance from anterior condylar point to orbitoauricular plane

MH (mm), the length of the ascending mandibular branch; V-S (mm), VC to the median sagittal plane; V-H (mm), mandibular length; SMA (°), angle of mandibular; CMA (°), the angle between the ascending mandibular branch and the sagittal plane; AMA (°), the angle between the mandibular body and the sagittal plane; P1, distance from posterior condylar point to sagittal plane; S1, distance from supracondylar point to sagittal plane; A1, distance from anterior condyle to sagittal plane; P2, distance from posterior condylar point to orbito-auricular plane; S2, distance from supracondylar point to orbitoauricular plane; A2, distance from anterior condylar point to orbitoauricular plane; CS, the uppermost point of condyle; VC, vertical angle point (the intersection point between the posterior edge of the ascending branch of the mandible and the lower edge of the mandible body); HC, horizontal angular point (the point at which the long axis of a cusp meets the lower mandibular margin, usually about 7 mm from the mental foramen); CP, last point of condyle.

personalized solid model. By using CAD/CAM image technology, a symmetrical mandible model of the affected side was made after the image conversion of the mandible data from the health test. The body thickness and diameters of the anterior and posterior ascending branches of the traditional mandible were measured with vernier calipers, and the measurement marks were the same as those of the mandible 3D reconstruction model.

Statistical methods

All indicators were fixed and measured by the same physician. The samples were measured 3 times at different time points, and all quantitative data were statistically described using mean ± standard deviation ($\bar{x}\pm s$). The software SPSS 25.0 (IBM Corp., Armonk, NY, USA) was used to conduct a paired t-test for preoperative and postoperative data on the healthy side or the affected side. A 2-sided P value ≤0.05 was considered statistically significant.

Results

A total of 364 patients who underwent mandibular reconstruction were analyzed. Among them, 143 patients received an iliac crest free flap with a mean age of 38.5 years (range, 14 to 71 years) and 221 patients received a fibular free flap with a mean age of 47.1 years (range, 13 to 72 years) (*Table 2*). Diagnoses of patients using iliac crest free flap were squamous cell carcinoma (70 patients), ameloblastoma (26 patients), odontogenic keratocyst (6 patients), osteosarcoma (5 patients), ossifying fibroma (1 patients), and other diseases (35 patients). Diagnoses of patients using fibular free flap were squamous cell carcinoma (12 patients), ameloblastoma (98 patients), odontogenic keratocyst (16 patients), osteosarcoma (4 patients), ossifying fibroma (8 patients), and other diseases (83 patients). Based on our 'VSCU' classification system, 23 patients underwent unsatisfied mandibular reconstruction were classified. Type V+SfC+U+ were
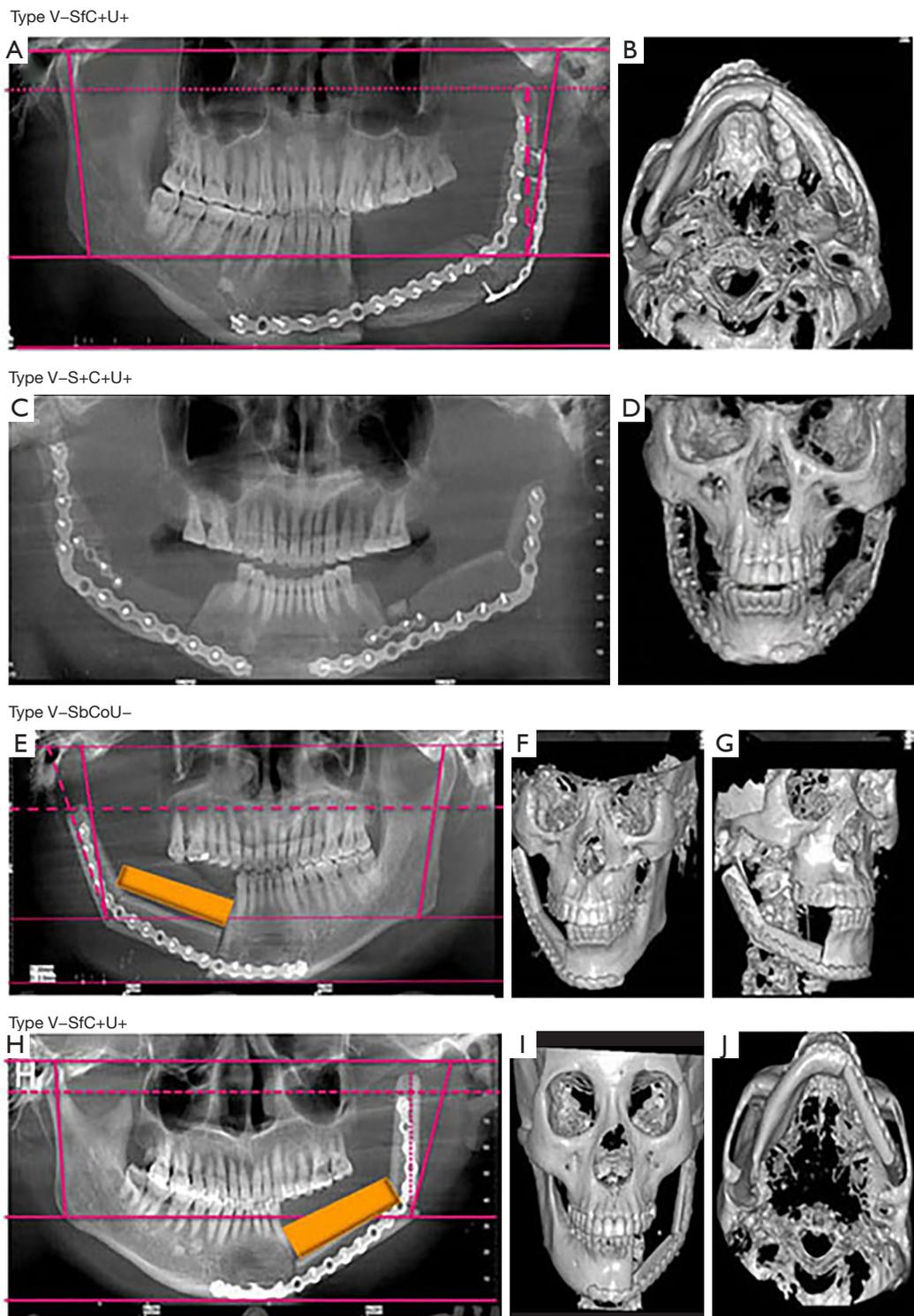
Type V–SfC+U+

Type V–S+C+U+

Type V–SbCoU–

Type V–SfC+U+

Figure 5 According to the "VSCU" classification system, 23 cases with unsatisfactory mandibular reconstruction were classified. (A) and (B) represent V–SfC+U+, (C) and (D) represent V–S+C+U+, (E-G) represent V–SbCoU–, and (H-J) represent V–SfC+U+. "VSCU" classification system, the system is based on the position of the condylar head on the V, S, C axis of the TMJ and Whether condylotomy was performed (U). V, vertical position; S, sagittal position; C, coronal position; U, unnecessary resection of the condyle; TMJ, temporomandibular joint.

Table 2 Basic information of enrolled patients

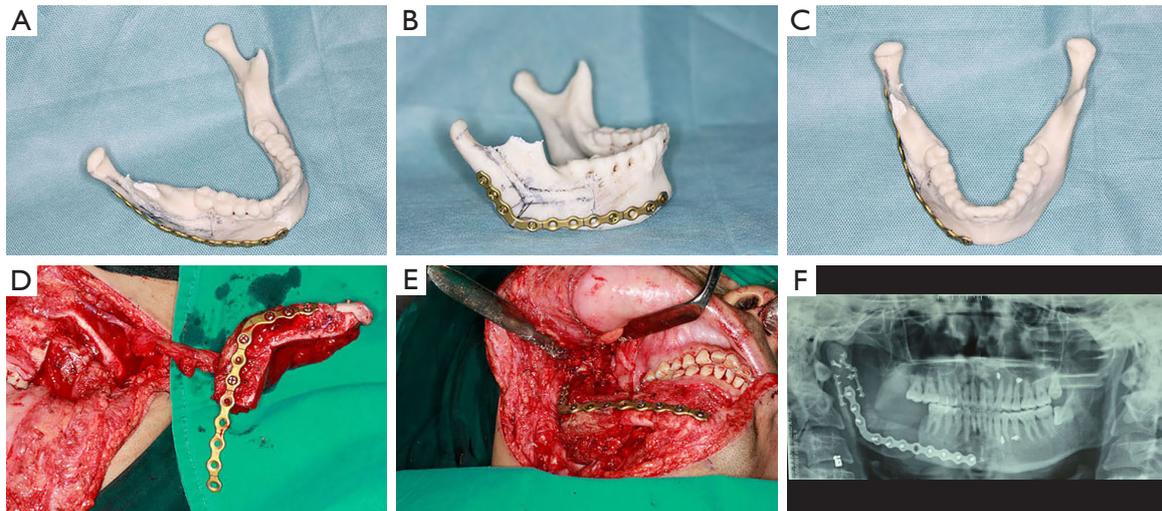| Reconstruction method/ surgical managements	Age, years [mean (range)]	Squamous cell carcinoma	Ameloblastoma	Odontogenic keratocyst	Osteosarcoma	Ossifying fibroma	Other diseases	Total
Iliac muscle flap	38.5 (14 to 71)	70	26	6	5	1	35	143
Fibular myocutaneous flap	47.1 (13 to 72)	12	98	16	4	8	83	221

Figure 6 The digital reconstruction of mandible and the image of mandible after reconstruction were carried out by CAD/CAM. (A-C) The reconstructed mandibular contour using digital surgical techniques and titanium plate prebending. (D-F) Intraoperative and postoperative images of the mandible and temporomandibular joint position after the use of digital surgical techniques. It can be seen that the mandibular shape and condyle position are well recovered. CAD/CAM, computer-aided design and manufacturing.

predominant (n=8), followed by type V–SfC+U+ (n=4), type V–S+C+U+ (n=3), type V–SbCoU– (n=3), type V–SbCoU– (n=2), type V–SbC+U+ (n=2), and type V–S+C+U– (n=1) (*Figure 4*). On the basis of summarizing the cases of poor mandibular reconstruction, we adopted the digital model surgery to carry out mandibular image reconstruction before surgery, and performed titanium plate prebending to ensure the shape and position of mandible and TMJ after reconstruction, with good results (*Figure 6*).

Mandibular morphology mainly consists of mandibular body length (V–H) and elevation. It is determined by branch height (MH), mandibular angle (SMA), ascending mandibular branch angle relative to the sagittal plane (CMA), and mandibular body angle relative to the sagittal plane (AMA). After measuring the indicators related to mandibular morphology after surgery and before surgery, the results showed that there was no statistical

significance in the changes of indicators on the healthy side and the affected side (*Table 3*). This result indicated that the mandibular bone morphology did not change significantly after surgery, because the design of the bone flap reconstruction scheme was based on the design of the preoperative or healthy mandibular morphology by 3D image.

The samples included in this study included 2 categories of bone defects with or without condyle involvement, so they were detected separately in different groups, and the changes of mandibular position relative to maxilla or cranial bone position after surgery were reflected by analyzing the changes of condyle position. The results showed that in mandibular reconstruction without condyle involvement, the condyle position on the healthy side had no statistical significance compared with the preoperative changes, whereas only the supracondyle point on the affected

Table 3 Mandibular morphology correlation test results (n=364)

Index	Healthy side			Affected side		
	Pre-operation	Post-operation	P value	Pre-operation	Post-operation	P value
SMA (°)	62.57±4.62	62.08±4.65	0.160	60.29±8.13	63.18±7.92	0.150
CMA (°)	3.50±4.77	2.94±4.87	0.200	3.87±3.48	5.14±4.85	0.220
AMA (°)	28.65±3.41	28.66±3.74	0.980	28.71±4.19	27.80±5.24	0.390
MH (mm)	62.22±5.39	62.33±5.21	0.520	62.21±5.25	59.52±8.72	0.060
V-S (mm)	47.73±5.02	48.37±5.03	0.150	48.25±5.12	48.95±5.61	0.460
V-H (mm)	76.57±5.30	76.31±5.52	0.560	91.53±14.81	91.33±15.08	0.900

Data are shown as mean ± standard deviation.   SMA (°), angle of mandibular;   CMA (°), the angle between the ascending mandibular branch and the sagittal plane;   AMA (°), the angle between the mandibular body and the sagittal plane; MH (mm), the length of the ascending mandibular branch; V-S (mm), VC to the median sagittal plane; V-H (mm), mandibular length; VC, vertical angle point (the intersection point between the posterior edge of the ascending branch of the mandible and the lower edge of the mandible body).

Table 4 Quantitative determination of condyle position after mandibular reconstruction without condyle involvement (n=364)

Index	Healthy side			Affected side		
	Pre-operation	Post-operation	P value	Pre-operation	Post-operation	P value
P1 (mm)	51.09±3.10	51.09±3.25	0.990	51.61±3.76	52.51±3.50	0.100
S1 (mm)	51.93±3.32	51.48±2.66	0.260	53.11±4.34	53.09±3.90	0.970
A1 (mm)	56.35±3.56	56.08±3.03	0.560	57.28±4.11	58.16±4.86	0.070
P2 (mm)	12.26±3.16	11.64±2.57	0.280	12.13±3.07	13.28±2.45	0.080
S2 (mm)	3.41±1.61	3.06±1.53	0.470	3.10±1.47	4.31±2.19	0.040
A2 (mm)	11.54±2.11	11.28±2.10	0.670	11.85±3.03	12.95±2.01	0.150

Data are shown as mean ± standard deviation. P1, distance from posterior condylar point to sagittal plane; S1, distance from supracondylar point to sagittal plane; A1, distance from anterior condyle to sagittal plane; P2, distance from posterior condylar point to orbito-auricular plane; S2, distance from supracondylar point to orbitoauricular plane; A2, distance from anterior condylar point to orbitoauricular plane.

side had statistical significance, which was manifested as downward movement of the supracondyle point (*Table 4*), indicating that in mandibular reconstruction without condyle involvement, the mandibular position on the healthy side and the affected side had no significant changes compared with the preoperative changes. There was no significant change in the position of condyle on the healthy side during mandibular reconstruction involving condyle. P1 on the affected side was 52.28±4.17 mm before operation and 58.94±5.65 mm after operation, P<0.01; P2 was 12.83±3.49 mm before operation and 24.90±7.15 mm after operation. S2 was 4.54±2.84 mm before operation and 19.10±8.54 mm after operation. A2 was 11.46±3.35 mm before operation and 24.15±8.29 mm after operation. The P values were all less than 0.01, and the differences were

statistically significant (*Table 5*). This result indicated that there was no significant change in the position of condyle on healthy side after mandibular reconstruction involving condyle. The posterior and superior points of the affected condyle shifted outward, and the posterior, superior, and anterior points of the condyle shifted downward.

Discussion

(I)   Since mandibular defects can lead to obvious functional and cosmetic deformities, the repair and reconstruction of mandibular defects has always been a challenge for surgeons (9-11). Reconstruction of mandible with vascularized free bone myocutaneous flap has become the gold standard for reconstruction

Table 5 Results of quantitative determination of condyle position after mandibular reconstruction involving condyle (n=364)

Index	Healthy side			Affected side		
	Pre-operation	Post-operation	P value	Pre-operation	Post-operation	P value
P1 (mm)	51.03±3.90	51.40±3.93	0.580	52.28±4.17	58.94±5.65	<0.01
S1 (mm)	50.71±5.38	51.09±5.08	0.290	51.08±4.02	56.03±4.94	0.020
A1 (mm)	57.75±5.05	58.25±5.18	0.430	58.45±4.47	56.56±6.06	0.430
P2 (mm)	10.81±3.29	10.70±2.67	0.770	12.83±3.49	24.90±7.15	<0.01
S2 (mm)	3.44±2.91	3.04±2.92	0.520	4.54±2.84	19.10±8.54	<0.01
A2 (mm)	11.55±3.79	10.63±3.12	0.230	11.46±3.35	24.15±8.29	<0.01

Data are shown as mean ± standard deviation. P1, distance from posterior condylar point to sagittal plane; S1, distance from supracondylar point to sagittal plane; A1, distance from anterior condyle to sagittal plane; P2, distance from posterior condylar point to orbito-auricular plane; S2, distance from supracondylar point to orbitoauricular plane; A2, distance from anterior condylar point to orbitoauricular plane.

surgery, which can greatly improve the aesthetic and functional capacity (1,2,12,13). The main causes of mandibular excision are as follows: squamous cell carcinoma, ameloblastoma, odontogenic keratocyst, osteosarcoma, and ossifying fibroma. At the same time, the more common surgical protocol is to use the free bone flap with blood vessels for repair and reconstruction. After operation, using vascularized free bone myocutaneous flaps can also maintain viability during postoperative radiotherapy and provide adequate bone for future implant rehabilitation (14). Many factors need to be considered for mandibular reconstruction using vascularized free bone myocutaneous flap, such as jaw height, shape, function, adequate muscle attachment, and neurovascular preservation. The restoration of mandibular function includes chewing, swallowing, oral ability and speech, and attempts to restore the patient to a pre-disease state, which is the ultimate goal of reconstruction. However, the limitation of mandibular reconstruction is often associated with TMJ dysfunction (15-17).

(II) TMJ position is affected by the position and placement of condylar head and the condylar head is a growth center for the mandible. It is difficult to re-create the complex anatomy of the TMJ with the resection of condylar head that involve disarticulating the mandibular condyle from the temporal bone and associated TMJ structures. In fact, some anatomic studies have demonstrated that malignancies of the mandibular ramus and body rarely involve the condylar head, and that the vascularity and supportive structures of the condylar head are sufficient to maintain viability and function (9,10). Indications for condylar removal during surgery are as follows: mandibular lesions involving condyle, accompanied by obvious organic destruction, and unable to be treated by other methods; condylar osteoma; condylar chondroma can be excised. In this study, the criteria for determining whether condyle would be preserved were as follows: (i) for mandibular benign tumors, the scope of lesion resection should be 1 cm outside the tumor boundary; if the scope of lesion involved the neck of the condyle, the condyle should be removed; if the scope of the lesion is not involved in the neck of the condyle, and there is no obvious abnormality of the condyle, the condyle can be removed surgically, frozen in liquid nitrogen for 3 times, then implanted into the articular fossa, and fixed with titanium plates and reconstructed bone ends. (ii) For mandibular malignant tumors, the scope of lesion resection should be 2–3 cm outside the tumor boundary. At this time, if the condyle or the neck of the condyle is overgrown, the condyle should be removed during surgery. Thus, resection of the condyle is seldom necessary and the preservation of condylar head in these immature patients will avoid the long-term problems associated with growth center loss. In mandibular reconstruction design, surgeons should first analyze the necessity of condylar head resection and try to preserve the anatomic position of the TMJ. When the condylar head must be disarticulated, it is important to

choose the appropriate donor site and achieve proper positioning of the new condyle (11,12). In this study, we considered that a pathologically tumor-free margin should be achieved during the operation, that is, no tumor cells were found at the incisal margin, indicating that the surgical resection was relatively clean, signifying that radical resection or complete resection of the tumor had been performed, and the probability of postoperative recurrence and metastasis was low. The temporalis and lateral pterygoid muscles are used to pull the anteroposterior and lateral movements of the mandible. We usually do not suture them back to the bone stump in the operation, because we first need to ensure the stability of the bone after reconstruction, and excessive pull is not conducive to the stability of the mandible and condyle after reconstruction. In the course of our operation, we will try our best to achieve a negative incisal margin in order to achieve a more satisfactory comprehensive treatment effect of the tumor. However, at the same time, we also fully considered the function of the TMJ, the postoperative occlusal relationship and the quality of life of the patients, so for some benign tumors of the mandible, we adopted condylar preservation or condylar freezing replantation for treatment.

(III) Our experience has found that limitations of technique can easily lead to an improper position of the TMJ. Patients who underwent mandibular resection and reconstruction with osteotomies performed "free-handed" intraoperatively. Segment lengths and position were determined intraoperatively from measurements of the resected mandible and resultant defect. We analyzed unsatisfied reconstruction of mandibular defects using Iliac crest or fibular free flaps from December 2012 to November 2019, and developed a system to classify the improper position of TMJ in these cases. Mandibular head position shift on vertical axis, sagittal axis, and coronal axis was evaluated and unnecessary resection of the condyle was noted. Condylar displacement ranging from 0 to 2 mm might be physiologically adjusted during the functional period, but more than 2 mm of condylar displacement often indicates the dislocation and excursion (13). Based on our 'VSCU' classification system, insufficient length of mandibular ramus is the most likely occurrence (V–, n=15), followed by the condyle shifts forward on the sagittal axis (Sf, n=12), unnecessary resection of the condyle (U–, n=6), the condyle shifts backward on the sagittal axis (Sb, n=5), and the condyle shifts outside on the coronal axis (Co, n=5). We think that the development of a systematic method of assessing, classifying, and summarizing the position of TMJ with unsatisfactory mandible reconstruction is essential to prevent TMJ dysfunction because of the complex reconstructive nature of mandible defects. Our surgical team generally does not use fat transplantation, except in the case of large soft tissue defects and for post-operative packing of dead space. In order to obtain the correct position of the medial condylar fossa, we usually make a mirror model of the patient's healthy mandible and condylar process before the operation, and create a guide plate to ensure the correct position of the medial condylar fossa during the operation.

(IV) Preservation of TMJ function after mandibular resection requires a thorough anatomic knowledge of the condyle and surrounding structures, as well as the biology of mandibular tumors. These structures are partly or completely destroyed, and the interactions between occlusion, condyle, joint fossa, disc, and masticatory muscles should be considered. These conditions result in compromises from the ideal prosthodontic rehabilitation and no single type of free flap is capable of coping with the wide variety of mandibular defects. Iliac crest and fibular free flaps are both popular options for mandible reconstruction. Iliac crest free flap is the workhorse donor site for mandible body or angle because the ipsilateral iliac crest has a natural contour that resembles the hemimandible (14). The height of the iliac crest is similar to that of the native dentate mandible, allowing for good support for dental rehabilitation and adequate lower lip position at rest, which improves oral competence (15). However, the fibula free flap remains the first choice for total or subtotal mandibulectomy. The fibula can provide 30 cm of bone length and allow for the creation of multiple osteotomies, making it versatile in its application for mandibular reconstruction (16). The fibula is also suitable for reconstruction of the condyle after resection. Its narrow tubular shape and dense cortical structure closely mimic those of the native condyle, enabling fitted placement into the

glenoid fossa without damage to the surrounding bony and soft tissue structures, such as the facial nerve (17). However, in this study, the fibula free flap was more often inferior in condyle position compared with the iliac crest bone graft.

(V) Several factors might affect the position of condylar head after surgery. The vascularized osteocutaneous free flap could be easily fixed at a maximum intercuspation of occlusion. Conversely, the condylar head position could not be thoroughly confirmed, due to limited visual accessibility. Enlarged error on the condyle compared with the midline of the mandible caused by intraoperative intermaxillary fixation for flap positioning could be easily assessed (3). In addition, the slender dimension of the fibula free flap might result in more prominent error. The fibula free flaps were used more often to restore large defect in oral cancer. The number and cutting plane of the osteotomies, bone-to-bone contact, and fibular segment lengths have varied widely over the years. Excessive fibula shaping can lead to bone deficiency, and the condyle may be pulled forward to fill the gap. Due to the reconstruction, different muscle groups might work only partly or not at all, which means that the resulting vertical force cannot be built up correctly, and displacement of the mandibular condyle may occur as healing progresses between bone segments (4,5,10).

(VI) Currently, CAD/CAM with the use of 3D printers is helpful in the planning of reconstructive surgery. The traditional measurement method generally transfers the head-shadow measurement model and maps the measurement data manually, whereas the CAD/CAM directly obtains the corresponding measurement data through the computer algorithm, rendering the measurement more accurate and convenient. As mandible reconstruction was highly accurate and precise considering the position of the jaw remnant, reconstructed bone, and condyle head, the use of CAD/CAM technology for mandibular reconstruction offers the following benefits: shorter operation planning time, increased accuracy during osteotomy, and low costs (18). The cases using CAD/CAM technology appeared to be less unsatisfied with the reconstruction compared with conventional technique and had less improper position of the joint in our experience. At the same time, in the surgical design of this study, we used 3D printing and imaging technology before surgery to create the occlusal guide, so as to ensure the stability of the postoperative occlusal relationship (19). These results indicate that there is no significant change in the mandibular position on the healthy side and the affected side after conventional reconstruction compared with CAD/CAM. In mandibular reconstruction involving condyles, there was no significant change in the position of condyles on the healthy side. After adopting this method, the repair effect of patients is significantly increased, and it has clinical significance and value. Conversely, because we found that the method was effective in some cases, we hope that this paper will not only reflect on the reasons for the failure of condylar repair and reconstruction, but also provide a solution to this problem, which can be combined with CAD/CAM for clinical promotion. Focus on TMJ position with the use of CAD/CAM technology will further push forward this promising surgical frontier.

Strengths and limitations

The advantage of this study is the summary of the experience of these patients with unsatisfactory repair, which is rarely reported in China and internationally. We subdivided the unsatisfactory cases of mandibular reconstruction into several subtypes, analyzed and explained the causes of their formation, and provided some experience for the selection and design of repair methods in subsequent clinical practice. The limitation of this study lies in the small number of cases, which may not cover all types of mandibular malrepair in clinical practice. It is still necessary to continue to collect clinical cases and summarize experience to better guide clinical practice. CAD/CAM and 3D printer technology were used in 203 cases, whereas traditional technology was used in 161 cases, because the treatment decision-making process also needs to take into account the patient's own requirements, economy, equipment, and other comprehensive factors. As clinicians, we will inform patients in detail about the different advantages, disadvantages, and costs of the 2 methods, and the final choice is still in the hands of patients themselves, so the number of different technology choices in this study was different. In addition, we acknowledge that limitations in clinical studies may result in the 'VSCU' classification system being unvalidated, and its applicability to other populations remains uncertain.

Conclusions

Mandible reconstruction has high accuracy and precision requirements. Compared with traditional methods, the CAD/CAM technique can effectively reduce the probability of poor reconstruction effect and unreasonable joint position. Meanwhile, the "VSCU" classification system can assist the clinical work well during the preoperative design and postoperative evaluation process. Therefore, the study of TMJ location using CAD/CAM technology combined with the "VSCU" classification system will further promote the development of mandibular reconstruction.

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Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://qims.amegroups.com/article/view/10.21037/qims-23-1444/rc

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://qims.amegroups.com/article/view/10.21037/qims-23-1444/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. This retrospective study was conducted in accordance with the Declaration of Helsinki (as revised in 2013) and was approved by the Medical Ethics Committee of the Affiliated Hospital of Qingdao University with the Human Ethics Approval Number [(2021) IEC (099)], and informed consent was provided by all participants.

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