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Research article

A new classification of mandible defects and condyle changed after mandible reconstruction with FFF

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A B S T R A C T

Objectives: To explore a new classification of mandibular defects and changes in the preserved condyle after mandibular reconstruction with free fibular flap(FFF).
Study design: We reviewed patients who underwent mandibular reconstruction with FFF from 2015 to 2021 and classified the mandibular defects into five categories: classI(unilateral-mandibular excluding condyle), classII(unilateral-mandibular including condyle), classIII(bilateral-mandibular excluding condyle), classIV(bilateral-mandibular including one condyle), and classV(bilateral-mandibular including both condyles). Cone Beam Computed Tomography (CBCT) data were collected preoperatively(T0), at 7–10 postoperative days(T1), 6 postoperative months(T2), and 1 post-operative year(T3). We calculated the condylar surface area, volume, and displacement.
Results: 62 cases were collected. The condylar surface areas and volumes in T2 and T3 values were lower than those of T0 and T1($P < 0.01$) The condylar displacement was the lowest in ClassI and the largest in ClassIV($P < 0.01$), while no significant differences in classesI-III($P < 0.05$). Displacement during T1-T0 was greater than that during T2-T0 and T3-T0($P < 0.05$).
Conclusion: Mandibular reconstruction with FFF results in displacement and alteration of the condyle within a time interval, and this alteration stabilizes after 6 months. Mandibular defects that do not reach the midline, surgical alteration to preserve the condyle are not required. However, when the defects cross the midline, the condyle should be preserved as much as possible.

1. Introduction

The mandible is located in the lower third of the face and is the only movable and largest bone in the maxillofacial region. It participates in most activities of the oral and maxillofacial regions [1]. Segmental mandibulectomy is occasionally required for patients with tumors, trauma, or osteomyelitis [2]. Several techniques have been used to reconstruct segmental mandibular defects, such as autogenous bone graft [3], tissue engineered bone [4], titanium implants [5], and distraction osteogenesis [6]. Vascularized autogenous bone grafting is the gold standard technique for mandibular bone grafts with free fibula flap (FFF); it is also considered the best donor bone and has been increasingly used in recent clinical practice [7].

With the advantages of shorter scanning time, lower radiation doses, and high image quality, CBCT is widely used in jaw bone diseases [8]. It is also the first choice to analyze three-dimensional (3D) changes in the temporomandibular joint (TMJ) and changes in condylar volume and position [9]. Studies on mandibular reconstruction with FFF in phase primarily focused on functional improvement [10] and on functional and morphological changes in the neocondyle [11]. Studies on preserved condyles have been limited to analyses of two-dimensional alterations and have only compared time intervals periods but not different types of condylar

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defects because there is no standard classification describing the relationship between the defect site and preserved condyles [12].

We aimed to quantitatively assess 3D changes in condylar position after mandibular reconstruction with FFF during different time intervals using CBCT. We have also proposed a new classification of mandibular defects based on the relationship between the condyle and defects, which can used to analyze the impact of different defect types on preserved condyles.

2. Patients and methods

2.1. Patients

We conducted a retrospective study to evaluate patients who underwent mandibular reconstruction using FFF at the Affiliated Stomatology Hospital of Guangxi Medical University (Nanning, China) from January 1, 2015 to October 31, 2021. Each patient signed the relevant consent form. This study was approved by the local ethics review board (NO.2022092).

Inclusion criteria: 1) mandibular reconstruction using FFF; 2) sequential CBCT documentations; 3) overall good health conditions to tolerate general anesthesia along with controlled local inflammation. Exclusion criteria: 1) <1 year of follow-up; 2) tumor recurrence or infection requiring reoperation during the follow-up period; 3) removal of the fibula for various reasons during the follow-up period; 4) defects including both condyles without retained condyles; 5) nonmandibular segmental defects.

2.2. New classification of mandibular defects

The new classification is based on the relationship between the defect site and the condylar process (Fig. 1). The classification includes Classes I–V. Class I: unilateral mandible excluding the condyle (Fig. 1(a)) . Class II: unilateral mandible including the condyle (Fig. 1(b)) . Class III: bilateral mandibular excluding condyle (Fig. 1(c)) . Class IV: bilateral mandibular including one condyle (Fig. 1(d)) . Class V: bilateral mandibular including both condyles (Fig. 1(e)) . Considering the abovementioned inclusion and exclusion criteria, Class V was excluded from the study because there were no retained condyles.

2.3. Surgical techniques

2.3.1. Conventional (CT) techniques

Removal area of the mandibular and the fibula length for defect reconstruction were determined via preoperative CBCT. An incision was created at the inferior border of the mandible to expose and completely remove the lesion. According to the surgeon's experience, the corresponding length of the fibula and vascular pedicle were removed, and the fibula was shaped according to the condition of the mandibular defect. The shaped fibula was fixed to the mandibular defect using titanium plates and nails. This procedure was performed by two teams and was entirely dependent on the experience of the surgeon.

2.3.2. Computer-aided design (CAD) techniques

The preoperative CT data of craniomaxillofacial and fibula were obtained, and the 3D models of the craniomaxillofacial and fibula bones were reconstructed. First, the mandibular osteotomy line and guide plate were designed according to the lesion using CAD (Fig. 2(a) and 2(c)). The fibular osteotomy guide plate was designed according to the mandibular defect (Fig. 2(e) and 2(f)). Second, the reconstruction guide plate was designed (Fig. 2(b) and (d). One fibular osteotomy guide plate (Fig. 3(b)) and mandibular osteotomy guide plate and reconstruction guide plate (Fig. 3(a)) were printed. Two teams performed the operation using the guide plates (Fig. 4 (a)-4(c)).

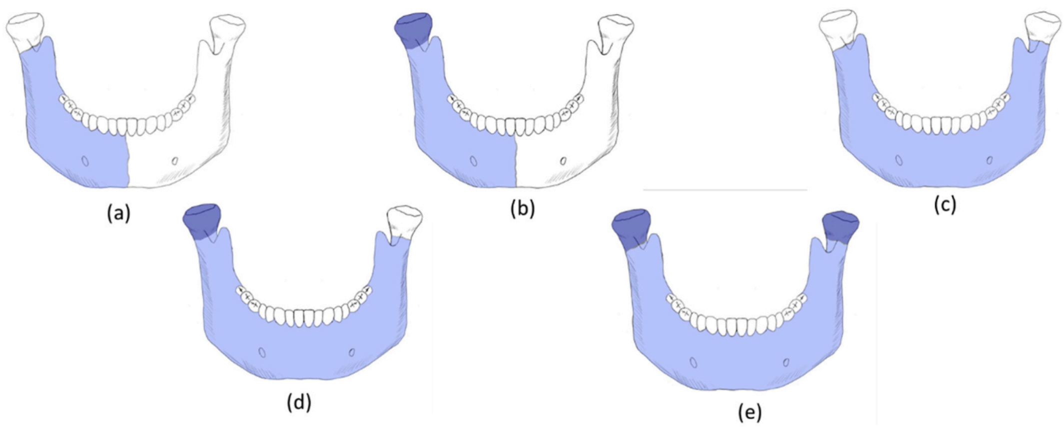


Fig. 1. The new classification of mandibular defects (a) Class I: Unilateral mandibular excluding condyle; (b) Class II: Unilateral mandibular including condyle; (c) Class III: Bilateral mandibular excluding condyle; (d) Class IV: Bilateral mandibular including one condyle; (e) Class IV: Bilateral mandibular including both condyles.

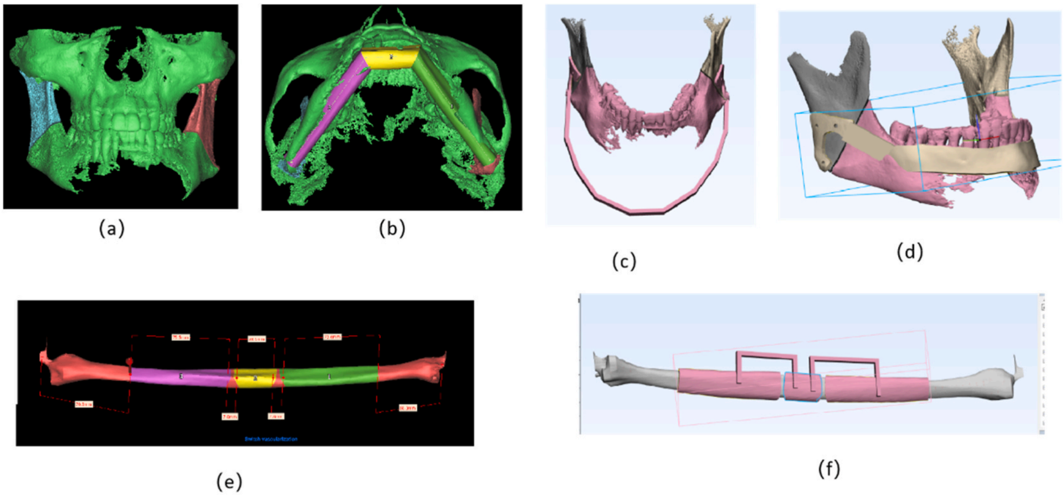


Fig. 2. Computer-aided design surgery. (a) Mandibular osteotomy line; (b) reconstruction plan; (c) mandibular osteotomy guide plate; (d) reconstruction guide plate (e) fibular osteotomy line; (f) fibular osteotomy guide plate.

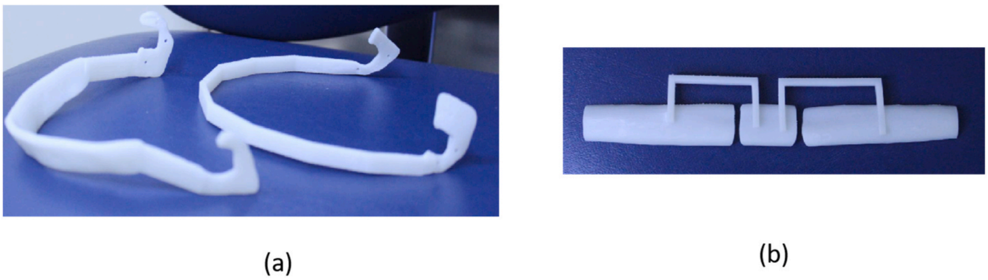


Fig. 3. Printed osteotomy guide plates. (a) Mandibular osteotomy and reconstruction guide plates; (b) fibular osteotomy guide plate.

2.4. Time intervals and imaging data acquisition

CBCT data were collected at four time intervals: preoperative (T0), 7–10 postoperative days (T1), 6 postoperative months (T2), and 1 postoperative year (T3). The data were saved in the digital imaging and communications in medicine (DICOM) format.

2.5. Condylar volume and surface area

CBCT images of the patients in intercuspal positions were collected and exported as DICOM files. The DICOM files were imported into the MIMICS software to reconstruct the 3D models of the upper and lower jaws at four time intervals. The condyle range was set according to the definition of the condyle by Tecco et al. [13]; that is, the lower edge of the condyle was segmented to the level of the sigmoid notch, and the upper edge was segmented to the condyle apex. At four time intervals, the condyle was segmented, and the condyle volume and surface area were calculated using the MIMICS at the relevant time intervals.

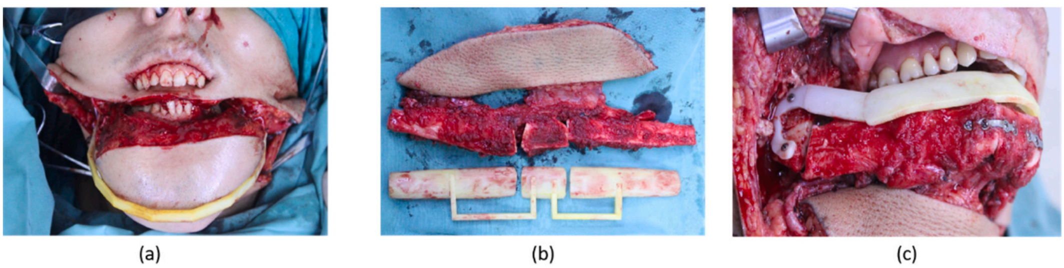


Fig. 4. Implementation of surgery. (a) Mandibulectomy according to the mandibular osteotomy guide plate; (b) fibula osteotomy according to the fibular osteotomy guide plate; (c) the fibula was fixed according to the reconstruction guide plate.

2.6. Measurement of condylar displacement

The changes in condylar position during different time intervals were compared using a 3D mapping technique. After mandibular osteotomy, the position of the craniomaxillary complex was unchanged and the CBCT image was captured in the intercuspal position. Therefore, the craniomaxillary complex (Fig. 5(a)) could be used as a reference to compare the 3D displacement of the condyle (Fig. 5(b)) at four time intervals. The FH plane was used as the reference plane to make the craniomaxillary complex at the four time intervals coincide infinitely, and the condylar displacement (Fig. 6(a)) before and after operation could be calculated (Fig. 6(b)).

2.7. Statistical analyses

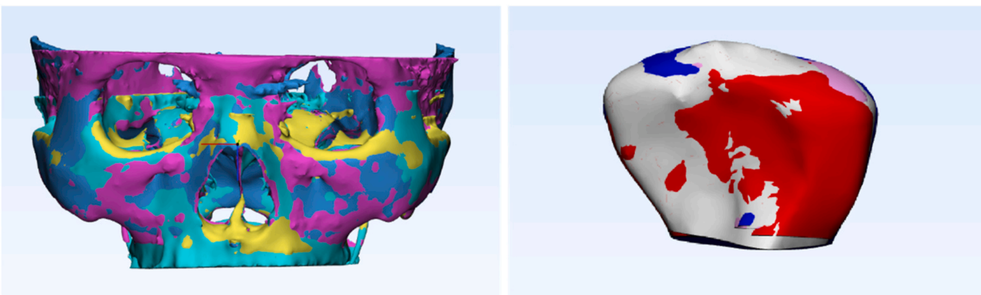
To reduce intraoperator error, all measurements were performed three times by the same person at different times (at least 1 week apart), and the average of the three measurements was considered. The normal distribution of the data was tested using the Shapiro–Wilk test. When the data conformed to the normal distribution, repeated measures ANOVA was used to analyze the data, and $P < 0.05$ was considered statistically significant. The data did not conform to the normal distribution and were analyzed using generalized estimating equations (GEE).

3. Results

The data of 62 patients were collected, including 29 men and 33 women aged 38.7 ± 15.9 years. There were 37 cases (59.7%) of benign lesions (ameloblastoma, ossifying fibroma, and odontogenic keratocyst). There were 16 cases (25.8%) of malignant tumors (squamous cell carcinoma and osteosarcoma). Radiation osteomyelitis occurred in 9 cases (14.5%). Forty-eight patients (77.4%) underwent surgery using traditional methods, and 14 patients (22.6%) were operated using CAD. There were 15 cases of Class I defect, 37 cases of Class II defect, 9 cases of Class III defect, 1 case of Class IV defect, and 0 cases of Class V defect. A total of 86 condyles were obtained, including 52 healthy-side condyles and 34 diseased-side condyles, one of which was dislocated from the glenoid fossa (Fig. 7).

Using repeated measures ANOVA, no significant differences were noted in the surface area of the diseased or healthy sides under different classification defects and surgical techniques ($P > 0.05$). However, there was significant differences at different time intervals ($P < 0.01$). No statistical significance was observed in the interactions between different time intervals, different bone defect classifications, and surgical techniques ($P > 0.05$) (Table 1). No significant differences were noted between T0 and T1. The condylar surface areas of the diseased sides at T2 and T3 were smaller than those at T0 and T1 ($P < 0.01$). The surface areas at T3 and T2 showed decreasing trend, but the results were statistically insignificant ($P > 0.05$; Table 2). The volume changes in the condyle are the same as those in the surface area (Tables 3 and 4).

Condylar displacement data did not conform to normal analysis and were analyzed using GEE. The displacement of the condyle on the diseased side was less using CAD than with using CT, but the data were not statistically significant ($P = 0.426$). Significant displacement of the condyle was noted under different classifications ($P < 0.01$), with the lowest displacement value in Class I and the largest displacement in Class IV. There were no statistically significant differences between Classes I and III ($P = 0.86$). The differences between Classes I and IV were statistically significant ($P < 0.01$), and the differences between Classes III and IV were statistically significant ($P < 0.01$). Condylar displacements during different time intervals were statistically significant ($P = 0.02$) and those of T1–T0, T2–T0, and T3–T0 were statistically significant, with T1–T0 being higher than the latter two ($P = 0.031$ and $P = 0.007$, respectively). The differences between T2–T0 and T3–T0 were not statistically significant ($P = 0.165$; Table 5). Comparing the displacements of the healthy-side condyle, no statistically significant differences were noted in different mandibular defect classes ($P = 0.698$) or at different time intervals ($P = 0.151$). A statistically significant difference was noted between different surgical techniques and condyle displacement, and the condyle displacement in the CAD group was significantly lesser than that in the CT group ($P = 0.004$; Table 6).



(a) (b)

Fig. 5. Preoperative and postoperative registration of mandibular and condylar processes. (a) Registration of maxillary, T0-yellow; T1-green; T2-purple; T3-blue; (b) registration of the condyle, T0-white; T1-blue; T2-red; T3-pink. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

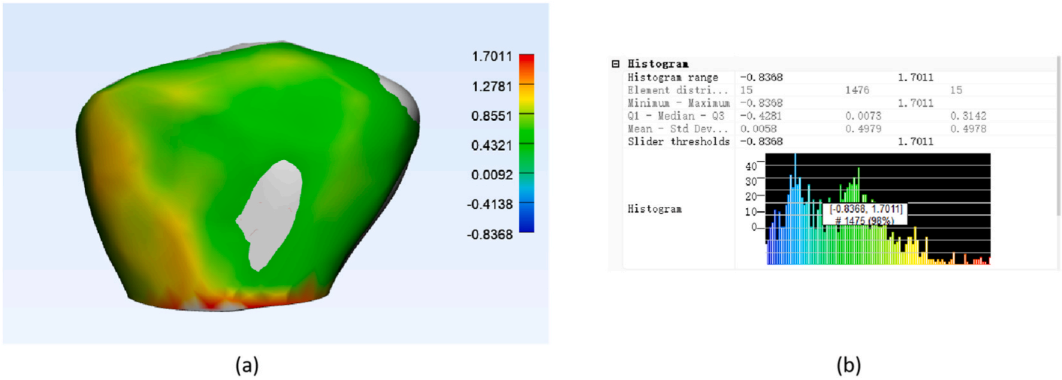


Fig. 6. Postoperative condyle displacement. (a) The histogram of condyle displacement. The value going upward from green indicated that the condyle protrudes outward postoperatively. The maximum value going downward from green indicated that the condyle was indented inward; (b) histogram figure. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

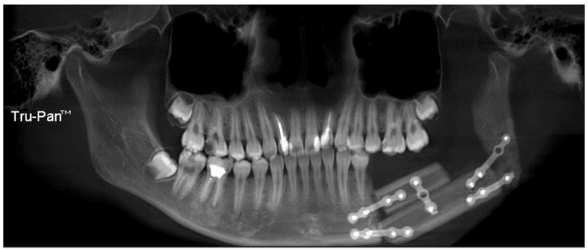


Fig. 7. The left condyle was dislocated from the glenoid fossa.

Table 1
Repeated measures ANOVA for the surface area of condyles.

	Surface area of the diseased-side condyles					Surface area of the healthy-side condyles				
	T0	T1	T2	T3	P values	T0	T1	T2	T3	P values
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD		Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	
Surgical Technique										
CAD	983.8 ± 170.2	990.6 ± 151.5	901.2 ± 123.6	914.9 ± 126.9		977.9 ± 138.5	975.1 ± 139.3	894.4 ± 134.1	882.5 ± 134.6	
CT	928.5 ± 221. 7	926.1 ± 217.3	832.81 ± 212.8	821.2 ± 230.1		916.8 ± 196.6	916.0 ± 206.3	840.2 ± 184.4	834.8 ± 188.3	
Classification of Defects										
Class I	926.5 ± 189.1	920.3 ± 178.8	812.7 ± 135. 5	807.7 ± 150.9		952.2 ± 192.9	941.0 ± 181.4	876.8 ± 172.0	869.7 ± 162.1	
Class II	/	/	/	/		922.3 ± 184.3	925.0 ± 200.2	842.9 ± 176.8	836.1 ± 184.3	
Class III	953.3 ± 237.8	953.2 ± 236.6	871.2 ± 246.3	862.3 ± 265.9		/	/	/	/	
Class IV	787.497	842.703	763.493	737.550		/	/	/	/	
Main Effect of Surgical Techniques					0.606					0.225
Main Effect of Classification of Defects					0.828					0.271
Main Effect of Time Interval					< 0.001					< 0.001
Interaction Effect of time intervals and Surgical Techniques					0.548					0.972
Interaction Effect of Time intervals and Classification of Defects					0.075					0.823

Table 2
Marginal estimated mean of different time intervals for the surface area of the condyles.

Periods	Surface area of the healthy-side condyles		Surface area of the diseased-side condyles	
	Mean ± SD	P values	Mean ± SD	P values
T0	963.8 ± 40.1	<0.001	938.0 ± 58.5	<0.001
T1	954.4 ± 42.6		944.4 ± 57.8	
T2	881.1 ± 38. 0		846.9 ± 54. 2	
T3	868.7 ± 38.6		839.1 ± 58.5	
T0 *vs.* T1		0.423		0.159
T0 *vs.* T2		<0.001		<0.001
T0 *vs.* T3		<0.001		<0.001
T1 *vs.* T2		<0.001		<0.001
T1 *vs.* T3		<0.001		<0.001
T2 *vs.* T3		0.383		0.353

Table 3
Repeated measures ANOVA for the volume of condyles.

	the volume of the diseased-side condyles					the volume of the healthy-side condyles				
	T0	T1	T2	T3	P values	T0	T1	T2	T3	P values
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD		Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	
Surgical Techniques										
CAD	2207.3 ± 591. 2	2208.3 ± 514.2	1957.0 ± 356.1	1953.6 ± 319.6		2106.4 ± 408.0	2064.4 ± 414.6	1908.8 ± 390.8	1878.7 ± 399.1	
CT	1940.4 ± 632.9	1929.6 ± 629.5	1723.5 ± 621.2	1693.5 ± 653.3		1889.6 ± 538.3	1875.3 ± 540.8	1712.8 ± 506.6	1684.9 ± 509.1	
Classification of Defects										
Class I	1942.0 ± 546.2	1899.5 ± 500.6	1650.4 ± 390.3	1628.9 ± 407.9		1977.2 ± 500.4	1951.5 ± 484.9	1810.8 ± 462.5	1798.2 ± 447.1	
Class II	/	/	/	/		1924.4 ± 527.8	1915.9 ± 537.4	1736.6 ± 499.7	1701.8 ± 508.5	
Class III	2045.8 ± 692.2	2054.4 ± 703.2	1867.2 ± 711.9	1837.9 ± 748.3		/	/	/	/	
Class IV	1353. 7	1497.5	1327.303	1299.2		/	/	/	/	
Main Effect of Surgical Techniques					0.398					0.160
Main Effect of Classification of Defects					0.734					0.290
Main Effect of Time Interval					<0.001					<0.001
Interaction Effect of Time Intervals and Surgical Techniques					0.157					0.858
Interaction Effect of Time intervals and Classification of Defects					0.102					0.676

Table 4
Marginal estimated mean of different time intervals for the volume of condyles.

Periods	Volumes of the healthy-side condyles		Volumes of the diseased-side condyles	
	Mean ± SD	P values	Mean ± SD	P values
T0	2032.3 ± 112.6	<0.001	1991.3 ± 162.5	<0.001
T1	2016.6 ± 113.7		1989.6 ± 163.3	
T2	1849.9 ± 106.4		1750.1 ± 156.3	
T3	1820.5 ± 106.0		1718.8 ± 164.9	
T0 *vs.* T1		0.290		0.925
T0 *vs.* T2		<0.001		<0.001
T0 *vs.* T3		<0.001		<0.001
T1 *vs.* T2		<0.001		<0.001
T1 *vs.* T3		<0.001		<0.001
T2 *vs.* T3		0.190		0.112

Table 5
Condylar displacement on the diseased side.

	Mean ± SD	P values
Surgical Technique		
CAD	0.756 ± 0.055	0.426
CT	0.996 ± 0.289	
Classification of Defects		
Class I	0.552 ± 0.207	<0.001
Class III	0.592 ± 0.151	
Class IV	1.483 ± 0.182	
Class I *vs.* Class III		0.860
Class I *vs.* Class IV		<0.001
Class III *vs.* Class IV		<0.001
Time Intervals		
T1–T0	1.191 ± 0.221	0.020
T2–T0	0.777 ± 0.144	
T3–T0	0.661 ± 0.137	
T1–T0 *vs.* T2–T0		0.031
T1–T0 *vs.* T3–T0		0.007
T2–T0 *vs.* T3–T0		0.165

Table 7 shows the overall condylar displacement. No statistically significant differences were observed in terms of different surgical techniques ($P = 0.179$); however, the CAD displacement was less than that with CT. Condylar displacement significantly differed between different defect classifications. Class IV displacement distance was significant compared to that of Classes I, II, and III, respectively ($P < 0.01$), and displacements of Classes I, II, and III were not statistically significant compared to each other ($P > 0.05$). The differences in condylar displacement during different time intervals were statistically significant; statistically significant differences were noted between T1–T0 and T2–T0($P = 0.008$), T1–T0 and T3–T0 ($P = 0.011$). No statistically significant differences were noted between T2–T0 and T3–T0($P = 0.711$); however, the T2–T0 displacement distance was more than the T3–T0 displacement distance.

4. Discussion

In 1989, Hidalgo [14] first proposed the use of vascularized FFF for mandible reconstruction, which has several advantages including convenient shape, sufficient length, low donor-site morbidity, and the formation of a skin island for soft-tissue defects. Thus, this method has several applications. Complications after mandibular reconstruction are common, and one of these is condylar dislocation [15]. Condylar dislocation may occur in the preserved condyle or in the neocondyle. Condyle dislocation occurred in one of our patients, which may be attributed to the surgeon's failure to carefully locate the condyle during the operation. The use of CAD can reduce the occurrence of this complication.

Several research papers have classified mandibular defects; however, no classification has been widely adopted. Jewer et al. [16] proposed the classification of mandibular defect as HCL in 1989, wherein H indicates hemimandible, referring to the lateral mandible defect including condyle; C indicates central defects including both canines; L for lateral mandible defect excluding the condyle. However, this classification was not applicable to edentulous jaws. Urken et al. [17] described a classification based on the anatomic sites. Letters were used for different sites: S for symphysis; B for body; R for ramus; and C for condyle. This classification was purely descriptive with too many combinations and groups, making it complicated to make comparisons. Brown et al. [18] recently proposed a classification of mandibular defects based on the four corners of the mandible (the canine region and mandibular angle), which revealed Classes I–IV: Class I indicated lateral mandibulectomy excluding the condyle and canine; Class II indicated hemimandibulectomy excluding the condyle, Class III indicated anterior mandibulectomy includes both canines, Class IV indicated extensive mandibulectomy including both canines at one or both angles. Classes Ic, IIc, and IVc referred to the subclassification of defects including condyles. This classification has been considered to reflect the complexity of the reconstruction. Iizuka et al. [19]

Table 6
Condylar displacement on the healthy side.

	Mean ± SD	P values
Surgical Techniques		
CAD	0.103 ± 0.060	0.004
CT	0.387 ± 0.071	
Classification of Defects		
Class I	0.263 ± 0.080	0.698
Class II	0.227 ± 0.041	
Time Intervals		
T1-T0	0.300 ± 0.063	0.151
T2-T0	0.197 ± 0.047	
T3-T0	0.239 ± 0.067	

Table 7
Results of overall condylar displacement.

	Mean ± SD	P values
Surgical Techniques		
CAD	0.526 ± 0.104	0.179
CT	0.694 ± 0.050	
Classification of Defects		
Class I	0.363 ± .0100	<0.001
Class II	0.232 ± .0052	
Class III	0.439 ± 0.130	
Class IV	1.407 ± 0.076	
Class I *vs.* Class II		0.168
Class I *vs.* Class III		0.657
Class I *vs.* Class IV		<0.001
Class II *vs.* Class III		0.193
Class II *vs.* Class IV		<0.001
Class III *vs.* Class IV		<0.001
Time intervals		
T1-T0	0.766 ± 0.094	0.024
T2-T0	0.542 ± 0.054	
T3-T0	0.523 ± 0.052	
T1-T0 *vs.* T2-T0		0.008
T1-T0 *vs.* T3-T0		0.011
T2-T0 *vs.* T3-T0		0.711

proposed a classification based on the number of osteotomies of the fibula flap, as Class I had no osteotomy of the fibula, Class II had one osteotomy, Class III had two osteotomies, and Class IV had multiple (more than two) osteotomies. This classification emphasized more on the reconstructive technique. The abovementioned classifications failed to mention the relationship between the location of the defect and the preserved condyle, as well as the influence of this location on the preserved condyle. However, mandibular defects often cause TMD symptoms, which are easily ignored. Therefore, we have proposed a new mandibular defect classification to evaluate the effect of different types of defects on the preserved condyle.

Class I (unilateral mandibular excluding condyle), refers to the defect location on any part of unilateral mandibular excluding the condyle. When this defect reaches the condyle (Class II), the midline (Class III), or one condyle and midline (class IV), the defect site changes. The preserved condyle changes from one diseased side and one healthy side to only one healthy side (Class II), two diseased sides (Class III), or one diseased side condyle (Class IV). This defect range of Class IV is wider than that of the other three classes, including one condyle and both sides of the mandible. Class V is the least common category in this paper or other literature [16–18].

The condylar volume and surface area were not significantly different among the four classes for the healthy side and the diseased side. Only one case of Class IV and the condylar displacement data was nonnormally distributed, the marginal estimated mean value in GEE was used for statistical calculation. The marginal estimated mean estimates the mean calculated from the sample based on the current model after fixing the effects of other factors. Even if the working correlation is incorrectly specified, the inferences will be asymptotically correct [20]. There were no significant differences in the displacement of different classes of defects when the preserved condyle was located on the healthy side; however, when the preserved condyle was located on the diseased side, the displacement of the condyle for different defect classifications significantly differed, with Class IV showed the largest displacement and Class I showing the smallest displacement. This indicated that larger the defect, the more difficult was the repair, the condyle displacement was greater. This is true for overall condylar displacement, with Class IV displacement being the largest. Wang et al. [21] found a positive effect of preserving the condyle on the TMJ; therefore, they proposed that the condyle should be preserved when benign mandibular lesions are located close to the condyle. Interestingly, our results showed that there was no significant difference in condylar displacement between Class I and Class II, and even the displacement of Class II was slightly lower than that of Class I, indicated that when the defect did not reach the mandibular midline, condylar resection had no effect on the preserved condylar displacement. The displacement of Class IV was significantly larger than that of Class III, indicated that when the mandibular defect crossed the midline, one condyle was removed, and the displacement of the preserved condyle was significantly increased.

The volume and surface area of the condyle changed with time. They significantly lessened within 6 months, and then gradually stabilized, irrespective of being on the healthy or diseased side. The displacement distance of the diseased condyle was statistically significant during different time. T1–T0 displacement was the largest, T2–T0 and T3–T0 displacement distances were smaller than T1–T0, and the differences between T2–T0 and T3–T0 were not statistically significant. Therefore, the displacement distances of the diseased condyles tended to be stable after 6 months. The displacement of the healthy condyle was not statistically different during different time; however, its volume and surface area changed with time, indicating that no difference in immediate condyle displacement but the existence of certain alterations over time. The effect of different surgical techniques on condylar volume, surface area, and diseased-side condyle displacement were not statistically significant. However, the surgical techniques affected the displacement of the healthy-side condyle; CAD displacement was significantly smaller than CT displacement, indicating that during conventional surgery, the surgeon is focused on the position of the diseased-side condyle but also needs to focus to the displacement of the healthy-side condyle. It has been reported that computer-assisted surgeries can be more precise and convenient along with having and shorter operative times [22]. However, these techniques also increase the financial burden on patients; thus, long-term studies are required.

There are still some limitations in this paper. First, the alteration and displacement of the preserved condyle after operation were quantitatively discussed. Because of the irregularity of displacement, the specific displacement direction of condyle was not discussed. The irregular condylar displacement may be related to the different surgical design of each surgeon, but the final results showed the alteration stabilizes 6 months after surgery, which is also consistent with the results of most literature [21,22]. Finally, we proposed a new classification of mandibular defects based on the relationship between the condyle and defects. The results showed that the larger the defect, the fewer number of cases, with 1 case in class IV and no case in class V. Improved statistical methods made the data more credible, multi-center studies should be considered in subsequent studies.

5. Conclusion

Mandibular reconstruction with FFF will cause displacement and alteration of the condyle over a certain period of time. This alteration generally stabilizes after 6 months without special treatment or intervention. This novel classification of mandibular defects demonstrates the five relationships between the preserved condyle and the location of the mandibular defect. Mandibular defects that do not reach the midline, surgical alteration to preserve the condyle are not required. However, when the defects cross the midline, for benign tumors, the condyle should be preserved as much as possible, even if the lesion is close to the condyle. We found that greater the extent of the defect, the greater was the condyle displacement. However, considering the relatively small sample size of Class IV, our results should be interpreted with caution.

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Data availability statement

All data generated or analyzed during this study are included in this article. There are no separate or additional files.

CRediT authorship contribution statement

Yaxi Wang: Writing – review & editing, Writing – original draft, Software, Resources, Investigation, Formal analysis, Data curation, Conceptualization. **Guosheng Chen:** Visualization, Data curation. **Nuo Zhou:** Visualization, Validation, Supervision, Funding acquisition. **Xuanping Huang:** Writing – review & editing, Supervision, Methodology, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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