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Evaluating the remodeling of condyles reconstructed by transport distraction osteogenesis in the treatment of temporomandibular joint ankylosis

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ABSTRACT

Purpose: This study aimed to evaluate the remodeling of condyles reconstructed by transport distraction osteogenesis (DO) in patients with temporomandibular joint (TMJ) ankylosis.
Patients and methods: Twenty-one patients with 26 affected joints were followed up for 34.1 ± 13.3 months. Patients who had undergone gap arthroplasty and TMJ reconstruction by DO were included. Maximal mouth opening (MMO) and occlusion were recorded. Computed tomography images were obtained preoperatively (T0), upon completing distraction (T1), upon removal of the distraction device (T2), and >2 years postoperatively (T3). The following were measured: mandibular ramus height, distance between gonion and Frankfurt plane (Go–FN), condylar width, and condyle–ramus angulation.
Results: Of the 21 patients, one showed re-ankylosis, while five exhibited anterior open bite. From T1 to T3, the total amount of resorption of ramus height reached up to 8.2 ± 4.6 mm ($p < 0.001$), in comparison with a total distraction length of 13.8 ± 4.1 mm; the mean resorption rate was 59.4%. Similarly, Go–FN decreased by 6.2 ± 4.0 mm ($p < 0.001$).
Conclusion: Our findings indicated that DO combined with gap arthroplasty was an effective method for the treatment of TMJ ankylosis to improve MMO. The reconstructed condyle exhibited a high frequency of resorption in height.

1. Introduction

Temporomandibular joint (TMJ) ankylosis is a bony or fibrous adhesion of the anatomical joint components by an ankylotic mass, with a manifestation of limited mouth opening (Jain et al., 2008; Allori et al., 2010; Bello et al., 2012; Kaur et al., 2015). It can be classified according to location (intra- or extra-articular), type of tissue involved (bone, fibrous, or fibro-osseous), and extent of fusion (complete or incomplete) (Rowe, 1982). Based on our previous study (Xia et al., 2019), it can also be classified into four types (I to IV) based on coronal computed tomography (CT) images.

The treatment of type III and IV ankylosis involves surgical interventions, including gap arthroplasty to achieve normal mouth opening, interposition arthroplasty to reconstruct the soft tissue separation between the glenoid fossa and condylar process, and/or joint reconstruction using autogenous grafts or alloplastic materials to restore ramus height and jaw occlusion (Kaban et al., 1990, 2009).

As a method of condylar reconstruction, transport distraction osteogenesis (DO) of the mandibular ramus has been utilized to form a condyle without the need for bone grafting, and was first recommended by Stucki-McCormick in 1997 (Stucki-McCormick, 1997). Several advantages of DO have been reported by previous studies, such as the opportunity for early postsurgical physiotherapy and simultaneous correction of secondary deformities

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(Stucki-McCormick et al., 1999). However, in one of our previous studies involving plain X-ray images, we noted that the heights of the reconstructed condyles were unstable in the long term; moreover, the mandible tended to be asymmetrical (Xiao et al., 2012). Similar surgical outcomes were reported by Kohli et al., in 2017, but the sample size in their study was small (Kohli et al., 2017). In addition, they did not analyze the amount of condylar resorption postoperatively from a three-dimensional (3D) perspective. It thus remains unknown how the transported segment was remodeled to form a condyle.

In this retrospective longitudinal study, our aim was to evaluate the remodeling of condyles reconstructed by transport DO in patients with TMJ ankylosis.

2. Material and methods

2.1. Patients

Our study included 21 patients admitted to the Department of Oral and Maxillofacial Surgery between January 2012 and January 2017. It was approved by the ethics committee of Peking University School and Hospital of Stomatology (no. PKUSSIRB-201416095).

The inclusion criteria were as follows: (1) age $\geq$ 14 years; (2) follow-up period $\geq$ 2 years; (3) type III and IV ankylosis, as confirmed by CT (Xia et al., 2019), which had to be treated with gap arthroplasty and TMJ reconstruction by DO; and (4) availability of complete clinical and imaging data.

The exclusion criteria were as follows: (1) age < 14 years; (2) patients lost to follow-up; (3) type I and II ankylosis, as confirmed by CT; and (4) TMJ reconstructed with autoplastic or alloplastic materials.

There were five bilateral and 16 unilateral cases, for a total of 26 affected joints. Of the 21 patients, 17 were males and four were females, with an average age of 29.8 ± 11.9 years (range, 14–66 years). Twenty cases were caused by traumatic ankylosis and one by uncertain etiology. The preoperative maximal mouth opening (MMO) was 8.7 ± 5.0 mm (range, 2–20 mm).

CT was performed with patients in the occlusal position preoperatively (T0), 1 month postoperatively upon completing distraction (T1), 6 months postoperatively upon removal of the distraction device (T2), and >2 years postoperatively (T3). Multiplanar reformation was used to generate coronal and 3D images of the TMJ (helix with 1.25-mm slice thickness; Bright Speed 16, GE Healthcare, Buckinghamshire, UK).

2.2. Surgical procedure

A preauricular incision was made to expose the TMJ region. A fissure drill was then used for osteotomy to create a 15–25 mm bone gap, which extended from the top of the glenoid fossa to the residual mandibular ramus (Fig. 1A). If the MMO did not reach 40 mm, arthroplasty of the other side or resection of the coronoid process was performed until >35 mm of passive MMO was achieved. The width of the gap was measured to determine the distance of distraction.

A temporal muscle myofascial flap was used to reconstruct the soft tissue separation between the glenoid fossa and condylar process (Fig. 1B). Simultaneously, an L-shaped osteotomy was performed on the mandibular ramus and DO was carried out to reconstruct the condyle (Fig. 1C). To achieve this, we ensured that the direction of transport DO was oriented to the floor of the glenoid fossa.

All surgeries were performed by the same surgeon, having approximately 30 years of experience in the surgical treatment of TMJ ankylosis.

2.3. Distraction and follow-up

After a latency period of 5–6 days, distraction of 1 mm/day was applied in three stages. When the distance between the transport segment and skull base reached 2 mm, the distraction was stopped to avoid any pressure on the flap. Patients were required to perform mouth opening exercises over 3 months, starting at 1 week postoperatively. After a consolidation period of 4–6 months, the distraction device was removed. All patients were followed up for 34.1 ± 13.3 months to review changes in MMO and mandibular remodeling.

Re-ankylosis was identified as heterotopic ossification visualized via CT images, along with MMO of <20 mm at the time of follow-up. Occlusion was recorded, and anterior open bite was defined as the lack of contact between the anterior teeth in centric relation. In addition, recent postoperative complications, such as infections, hemorrhage, or facial nerve injury, were recorded by reviewing medical records.

2.4. Metric analysis

Using ProPlan CMF 3.0 (Materialise, Leuven, Belgium), CT data were used to construct a 3D coordinate system based on the exact craniofacial midsagittal plane. The Frankfurt plane was adjusted parallel to the horizontal plane, and the following measurements were made: (1) mandibular ramus height was measured as the distance from gonion to condylion (Go–Co); (2) mandibular location was measured as the distance between the gonion and the Frankfurt plane (Go–FN); (3) condylar width was defined as the distance between the internal and external poles of the reconstructed condyle; (4) condyle–ramus angulation was measured as the angle between the posterior edge of the ramus and the line connecting the internal and external poles of the reconstructed condyle; and (5) airway width was measured as the narrowest anteroposterior diameter of the glossopharyngeal cavity (Fig. 2).

3D morphology of the reconstructed condyles was evaluated and classified.

All the aforementioned parameters were measured three times each by three separate examiners (blinded method). The minimum measurement interval was 1 week. The reliability of the test was determined by coefficient of internal consistency using the Kappa value.

2.5. Statistical analysis

Data were analyzed using paired t-tests and analysis of variance for statistical significance of longitudinal comparisons. Statistical analysis was conducted using SPSS 19.0 (SPSS Inc., Chicago, IL, USA). $p < 0.05$ indicated significance.

3. Results

3.1. Treatment results

All 21 patients underwent surgical treatment for the 26 affected joints, and there were no intraoperative complications. The follow-up period for all patients was 34.1 ± 13.3 months (range, 24–71 months). The interval between T2 and T3 was 27.8 ± 13.1 months

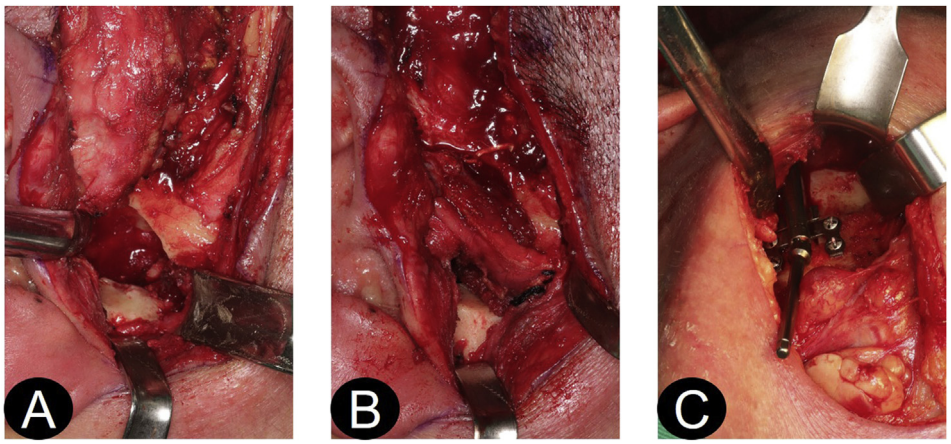

Fig. 1. Surgical procedure. (A) A 15–25 mm bone gap extending from the top of the glenoid fossa to the residual mandibular ramus. (B) The temporal muscle myofascial flap served as an interposition material. (C) L-shaped osteotomy on the mandibular ramus and distraction osteogenesis.

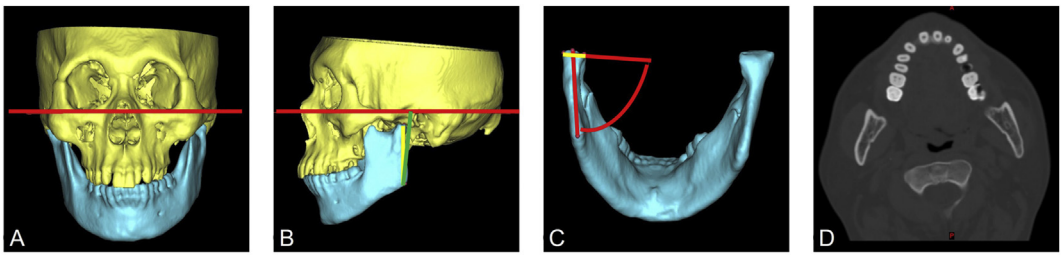

Fig. 2. Method of metric analysis. (A) The Frankfurt plane was adjusted parallel to the horizontal plane. (B) Ramus height was measured as the distance from gonion (Go) to condylion (yellow line), and mandibular location was measured as the distance between Go and the Frankfurt plane (green line). (C) Condylar width (yellow line) and condyle–ramus angulation, measured as the angle between the posterior edge of the ramus and the line connecting the internal and external poles of the condyle. (D) The narrowest anteroposterior diameter of the glossopharyngeal cavity.

Fig. 3. One patient exhibiting anterior open bite. (A) Improvement in maximal mouth opening of 23 mm, with normal occlusion at the time of distractor removal. (B) Maximal mouth opening of 48 mm with anterior open bite 4 years postoperatively.

(range, 18–63 months). MMO at the latest follow-up was 31.2 ± 8.3 mm (range, 5–45 mm), with 20 patients (95.2%, 20/21) showing values of >20 mm; one patient (4.8%, 1/21), however, showed a value of only 5 mm after 4 years, with re-ankylosis confirmed by CT examination. Five patients (23.8%, 5/21) exhibited anterior open bite at follow-up (Fig. 3). There were no complications in the form of postoperative infections, hemorrhage, or facial nerve injury (Table 1).

3.2. Measurement results

In the 20 patients without re-ankylosis (Table 2), the affected ramus height decreased by 5.1 mm from T1 to T2 ($p < 0.001$) and by 3.1 mm from T2 to T3 ($p < 0.001$). The total amount of resorption reached 8.2 mm, in comparison with a total distraction length of 13.8 mm, with a mean resorption rate of 59.4%. Similarly, Go–FN declined by 3.6 mm from T1 to T2 ($p < 0.001$) and by 2.6 mm from T2 to T3 ($p < 0.001$) (Fig. 4). On the other hand, condylar width increased significantly, by 1.9 mm, from T1 to T2 ($p = 0.004$), while condyle–ramus angulation decreased by 3.6° from T1 to T2 ($p = 0.006$) (Fig. 5).

3D image overlap showed the resorption of the reconstructed condyle in the vertical direction, with the entire mandible rotating as compensation (Fig. 6).

3.3. Classification of condylar morphology

Based on coronal CT and 3D reconstruction imaging (Fig. 7), all the reconstructed condyles at T3 were classified into three types: upright (76%, 19/25), medially bending (12%, 3/25), and complete resorption (12%, 3/25).

Table 1
Basic information pertaining to patients.

	$n = 21$
Age (years)	29.8 ± 11.9
Follow-up duration (months)	34.1 ± 13.3
Gender	
Male	17
Female	4
Affected side	
Bilateral	5
Unilateral	16
Etiology	
Traumatic	20
Unknown	1
MMO (mm)	
Preoperative	8.7 ± 5.0
Intraoperative	40.1 ± 3.2
Postoperative	31.2 ± 8.3
Distance of distraction (mm)	13.8 ± 4.1
Complications	
Re-ankylosis	1 (4.8%)
Anterior open bite	5 (23.8%)

4. Discussion

Type III/IV ankylosis is characterized by the entire joint presenting with bony fusion, without recognizable condyle and fossa (Xia et al., 2019; Sawhney, 1986). Treatment includes gap arthroplasty to recover normal mouth opening, interposition arthroplasty to create a physical barrier, and/or joint reconstruction using autogenous grafts or alloplastic materials to restore the ramus height and jaw occlusion (Kaban et al., 1990, 2009). Surgical treatment depends on the extent and type of ankylosis, age of the patient, onset and time of surgery, and whether the ankylosis is unilateral or bilateral. There is still no consensus on the ideal treatment modality for this debilitating condition, and no single method has been reported to consistently generate successful results (Khadka and Hu, 2012; Ma et al., 2015; Al-Moraissi et al., 2015; De Roo et al., 2016).

Transport DO for TMJ reconstruction was first applied by Stucki-McCormick in 1997 in two patients with tumors involving the condyle (Stucki-McCormick, 1997). Unlike bone grafting, mandibular ramus DO is efficient at reconstructing a neocondyle by lengthening the ascending ramus, with optimal new bone regeneration. Since then, numerous studies have reported that transport DO combined with gap arthroplasty markedly improves MMO, and has an extremely low rate of re-ankylosis (Yoon and Kim, 2002; Liang et al., 2002; Spagnoli and Gollehon, 2006; Mehrotra et al., 2012). In addition, Cheung and Lo and Chen et al. used a vector-locating splint and surgical templates to register the position and angulation of the distractor over the mandibular ramus and gonial angle region, respectively (Cheung and Lo, 2007; Chen et al., 2018). In the studies conducted by Eski et al. and Feiyun et al. bidirectional DO was utilized to correct deformities; Eski et al. reported that although vertical distraction corrected vertical deficiency of the ramus and created a neocondyle, the simultaneous anteroposterior distraction of the transport segment corrected facial asymmetry resulting from horizontal shortness of the mandible (Eski et al., 2008; Feiyun et al., 2010). Sahoo et al. compared DO with costochondral graft for the reconstruction of the ramus condylar unit and reported similar results (Sahoo et al., 2012). Furthermore, Liang et al. reviewed 73 patients who underwent transport DO arthroplasty and found that as high as 19.4% of patients under the age of 15 years showed recurrence (Liang et al., 2013).

To date, only few studies have evaluated the long-term stability of reconstructed condyles, and even in these, the sample sizes have been small. In a study conducted by Tuzuner-Oncul and Kisnisci, lateral and posteroanterior cephalograms were taken postoperatively before active distraction. The authors reported that the vertical lengthening of the ramus through ramus/condyle unit DO maintained the initial vertical ramus height gained for 24 months (Tuzuner-Oncul and Kisnisci, 2011). Furthermore, in a study by Xu

Table 2
Measurement results.

	T0	T1	T2	T3	*p-value* T1–T2	*p-value* T2–T3
Go–Co (mm)	/	60.0 ± 5.5	54.9 ± 4.6	51.8 ± 5.0	<0.001	<0.001
Go–FN (mm)	64.2 ± 6.5	65.4 ± 5.8	61.8 ± 5.3	59.2 ± 5.7	<0.001	<0.001
Condylar width (mm)	/	11.7 ± 3.3	13.6 ± 4.5	14.1 ± 4.6	0.004	0.518
Condyle–ramus angulation (°)	/	83.7 ± 5.0	80.1 ± 7.9	79.4 ± 5.9	0.006	0.694
Airway (mm)	6.1 ± 2.3	6.3 ± 2.2	6.5 ± 2.3	6.1 ± 2.1	0.517	0.418

One case of recurrence has not been included.
T0, preoperatively; T1, 1 month postoperatively upon completing distraction; T2, 6 months postoperatively upon removal of the distraction device; T3, >2 years postoperatively.

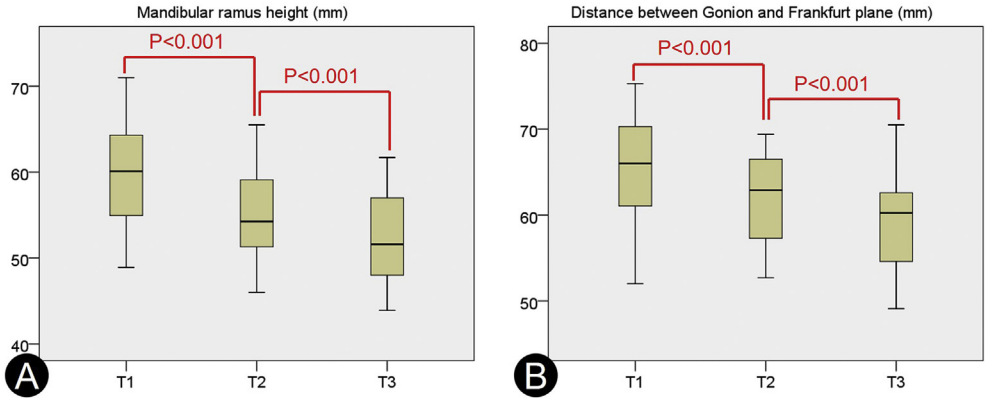

Fig. 4. Box-plot diagram for mandibular ramus height and distance between gonion and Frankfurt plane. Significant differences were found between both T1 and T2 and between T2 and T3.

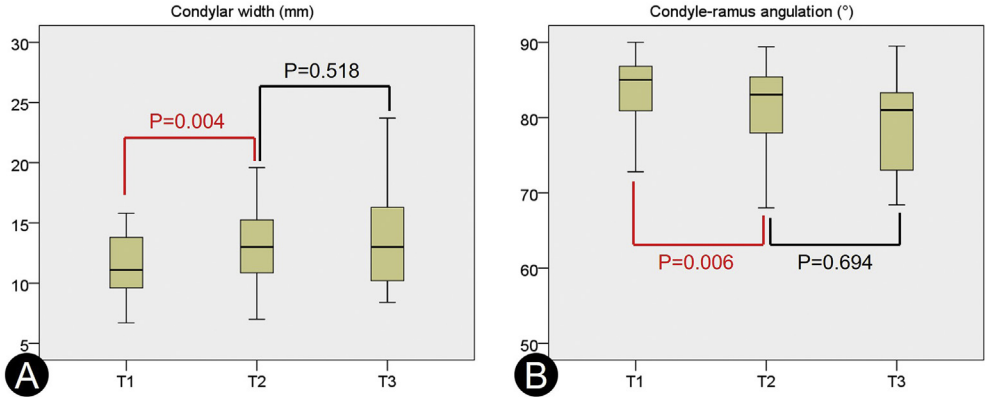

Fig. 5. Box-plot diagram for condylar width and condyle–ramus angulation. A significant difference was absent between T2 and T3 but present between T1 and T2.

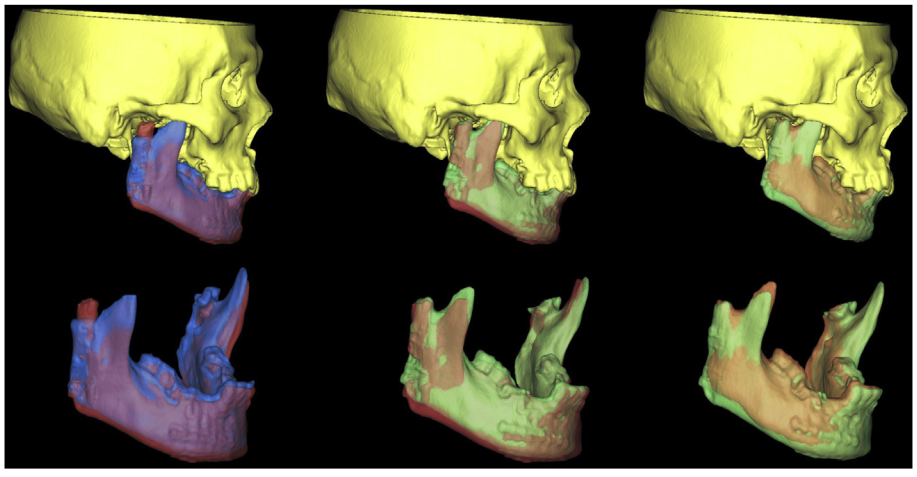

Fig. 6. Three-dimensional image overlap of the mandible: after installation of the distraction device (blue); at the end of the distraction interval (red); after removal of the device (green); and >2 years postoperatively (orange).

et al. no adverse TMJ condylar head complication was found (Xu et al., 2015). Nevertheless, we previously reported that plain X-ray images revealed the heights of reconstructed condyles to be unstable in the long term, with the mandible tending to be asymmetrical (Xiao et al., 2012). Similar results were reported by Kohli et al. they found the mean condylar resorption in the DO group to be 7.0 mm at 6 months postoperatively (Kohli et al., 2017).

In this study, the heights of reconstructed condyles were unstable, as resorption was found not only between T1 and T2 but also between T2 and T3. The mean resorption rate was as high as 59.4%; in some cases it even reached 100%. The resorption caused shortening in the affected side of the ramus, resulting in the entire mandible rotating as compensation. Similarly, a decrease in the bilateral mandibular ramus height was associated with a clockwise rotation of

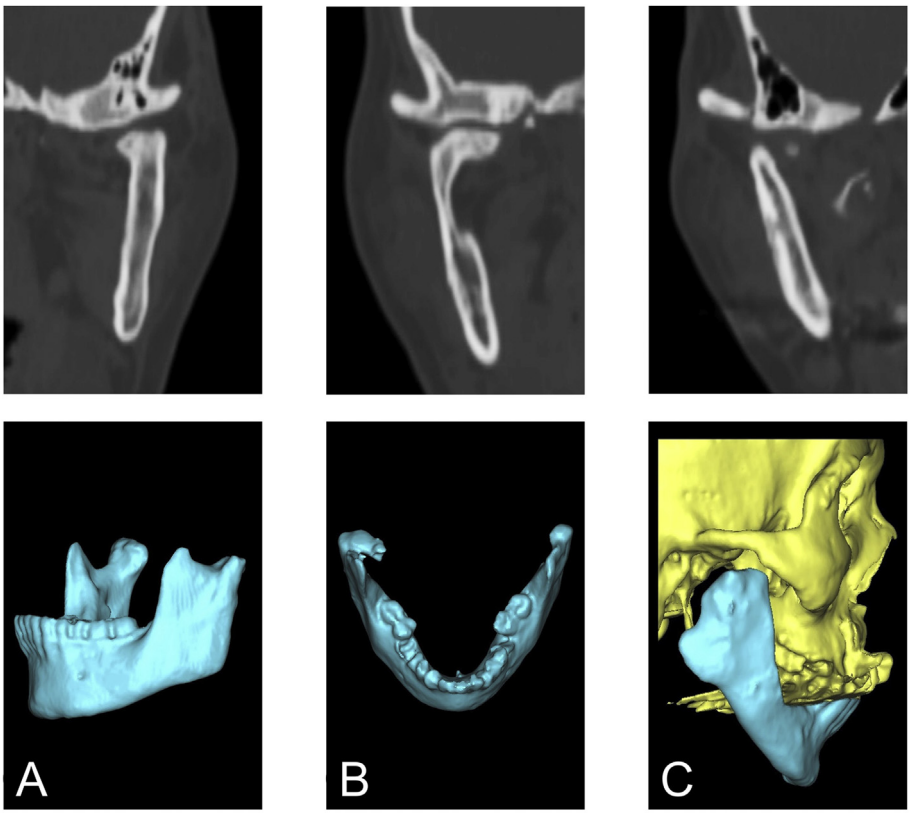

Fig. 7. Classification of the reconstructed condyle: (A) upright type, (B) medially bending type, and (C) complete resorption type.

the mandible, with a clinical manifestation of anterior open bite. The resorption of the reconstructed condyle in the vertical direction could be attributed to any of the following: (1) blood supply of distracted bone segments was a prominent factor; (2) distance or direction of distraction may have affected stability; (3) strength of internal fixations supported by distractors was not sufficiently rigid to stabilize the bone segments; and (4) the temporal muscle myofascial flap was not functionally equivalent to the articular disc.

Anterior open bite is a common complication after gap arthroplasty or interposition arthroplasty without joint reconstruction, when the ankylosing mass is so large that its resection is bound to considerably compromise the ramus height (El-Sheikh, 1999; Matsuura et al., 2001; Erol et al., 2006; Vasconcelos et al., 2009). This complication is rarely observed in the treatment of joint reconstruction, and only a few cases have been reported following ramus DO (Schwartz and Relle, 2008). However, in our study, we found that up to five of the 21 patients exhibited anterior open bite. This could be attributed to the resorption and remodeling of the condyle, leading to shortening of the ramus and resulting in the entire mandible rotating as compensation. The anterior open bite could be due to: (1) noncompliance of patients with postsurgical physiotherapy, coinciding with intermaxillary fixation; and (2) posterior tooth anodontia combined with unstable occlusion. Therefore, timely and effective orthodontic treatment and dental restoration after surgery should help to achieve satisfactory results, and may even have a preventive effect concerning condylar resorption.

The reconstructed condyles in this study could be classified into three types. The upright type, forming the majority, was considered to be the ideal morphology. The medially bending type, which was the first to be identified, could be due to excessive removal from the fossa area, while an unsatisfactory direction of DO could result in functional contact occurring in the medial region instead of in the anterior oblique plane of the condyle. The complete resorption type was the least desirable morphology, with this outcome perhaps considered equivalent to that obtained upon merely performing gap arthroplasty without any joint reconstruction.

Despite our important findings, this study has a few limitations. (1) As this was a retrospective study, lateral and posteroanterior cephalograms were unavailable; thus, we were unable to use the method of cephalometric analysis to confirm if the mandible tended to be asymmetrical. (2) Not all patients received timely and effective orthodontic treatment and dental restoration, which would have been beneficial for normal occlusion as well as the stability of TMJ function. (3) Better results would have been achieved if gap arthroplasty and distraction osteogenesis had been performed in separate sessions, but this would have increased the burden in terms of both time and cost. (4) Whether the three types of morphology showed a steady structure and function was unknown; this could be because the follow-up period was only 34.1 months and the sample size was small. (5) In this study, when the distance between the transport segment and skull base reached 2 mm, distraction was stopped to avoid any pressure on the temporal muscle myofascial flap. Whether overcorrection or over distraction could offset the resorption in condylar height needs to be confirmed. Therefore, further studies with a larger sample size and longer follow-up periods are warranted. Nonetheless, to the best of our knowledge, this is the first study to report the 3D remodeling of condyles reconstructed by transport DO in the treatment of TMJ ankylosis.

5. Conclusion

Our findings indicated that DO combined with gap arthroplasty is an effective method for the treatment of TMJ ankylosis to

improve MMO. The reconstructed condyle exhibited a high frequency of resorption in height.

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Declarations of interest

No conflicts of interest.

Acknowledgements

None.

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