

ARTICLE

Use of anterior ramus bone graft for mandibular reconstruction in elderly patients

Dan Yu^a , Jianyao Huang^b, Changyang Yu^c, Jianhua Liu^a, Chee Weng Yong^d and Huiyong Zhu^a

^aDepartment of Oral and Maxillofacial Surgery, the First Affiliated Hospital, Zhejiang University School of Medicine, Hangzhou, People's Republic of China; ^bDepartment of Stomatology, Fourth Affiliated Hospital Zhejiang University School of Medicine, Hangzhou, People's Republic of China; ^c6D Dental Tech Co., Ltd., Hangzhou, People's Republic of China; ^dFaculty of Dentistry, Discipline of Oral Maxillofacial Surgery, National University Centre for Oral Health Singapore, Singapore, Singapore

ABSTRACT

In this study, we investigated the feasibility of using a geometrically designed anterior ramus graft to reconstruct lateral mandibular defects. This was achieved by assessing the anatomical dimensions of the mandibular ramus on computed-tomographies. The design sequence and application of the graft was also demonstrated using one of our cases. The following dimensions were measured; a and b - horizontal length from mid-ramus to the posterior and anterior ramus border respectively, c - longest length of the graft, Mp - width at the centre of the ramus, h - vertical length of the angle at its cross-section, w - horizontal length of the angle at its cross-section, x - cross-sectional area along the mandible angle. A total of 80 mandibular rami were examined. The mean length of a , b , c were 17.3 ± 1.8 mm, 15.9 ± 1.2 mm, 54.6 ± 3.8 mm, respectively. The mean width of Mp was 9.8 ± 1.1 mm. The mean cross section area of $Eo-Md(x)$ was 326.7 ± 67.8 mm². The average length of h and w were 26.5 ± 3.2 and 15.6 ± 2.1 mm, respectively. The use of virtual surgical planning (VSP) to geometrically design the graft was also described. Together with VSP, the anterior ramus bone graft will allow for reconstruction of the mandible with greater surgical efficiency, reduced complexity and without the need for extra-oral bone harvest. This may be a useful alternative in situations where simpler reconstructive procedures are preferred.

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1. Introduction

The posterior mandible is a site where tumours and cysts commonly occur [1,2]. Large or aggressive pathologies may require resection surgeries, resulting in the discontinuity of the jaw. This is especially so for atrophic mandibles. The mandible plays a significant role in facial aesthetics, and is also involved in many functions such as mastication, swallowing and speech [3,4]. The role of reconstructive surgery is therefore critical in restoring the patients to their pre-morbid state [5].

Autogenous bone grafting is the gold standard material for bone regeneration [6,7]. For mandibular defects, a vascularised fibula flap may be the preferred choice [8,9]. The alternative would be a gap-bridging plate accompanied with a myocutaneous flap. While bridging the gap with only a reconstructive plate is possible, it is associated with many complications and is not amenable to subsequent dental prosthesis [10,11]. Non-vascularised bone grafts harvested from extra-oral sites can also be used to reconstruct mandibular defects in patients [12]. Extra-oral harvests are accompanied by increased morbidity and technical difficulty such as multiple surgical sites, extended duration of the operation, increased risk of infections, disfigurement of harvest sites or even permanent disabilities [13,14].

Longer or more complex surgeries may not be suitable for some patients whose compensatory mechanism to surgical stress is poor. This includes elderly patients, and especially so for those with multiple pre-existing comorbidities. In some situations, the physical condition of the potential harvest sites may impede their use. This may be due to osteoporosis, history of fracture, venous

stenosis or previous prosthetic surgery. Also, another common concern for the elderly is the risk of impeding their mobility [12,15,16].

In this article, we investigated the use of non-vascularised anterior ramus grafts to reconstruct lateral mandibular segmental defects. This approach can be an alternative to situations whereby there is a need to simplify the surgery or when extra-oral bone harvests are deemed unsuitable. At the same time, it overcomes the problem of gap-bridging plates without significant increase in risks and surgery time. Using a case as a sample, we have also demonstrated the use of Virtual Surgical Planning (VSP) to maximise the ramus graft for reconstruction.

2. Materials and methods

2.1. Reference points and lines

This study was performed in accordance with the Declaration of Helsinki and was approved by our hospital's human research ethics committee (Reference number 2017-400-1). 40 patients who have an existing Computed Tomography (CT) scan of the maxilla-mandibular region, taken from January 2015 to January 2017, were used for this study. The inclusion criteria were as follows:

- i. No obvious facial asymmetry
- ii. No previous pathology, injury or surgical intervention to mandible ramus
- iii. Age >60 years old
- iv. Missing at least the first, second and third molars

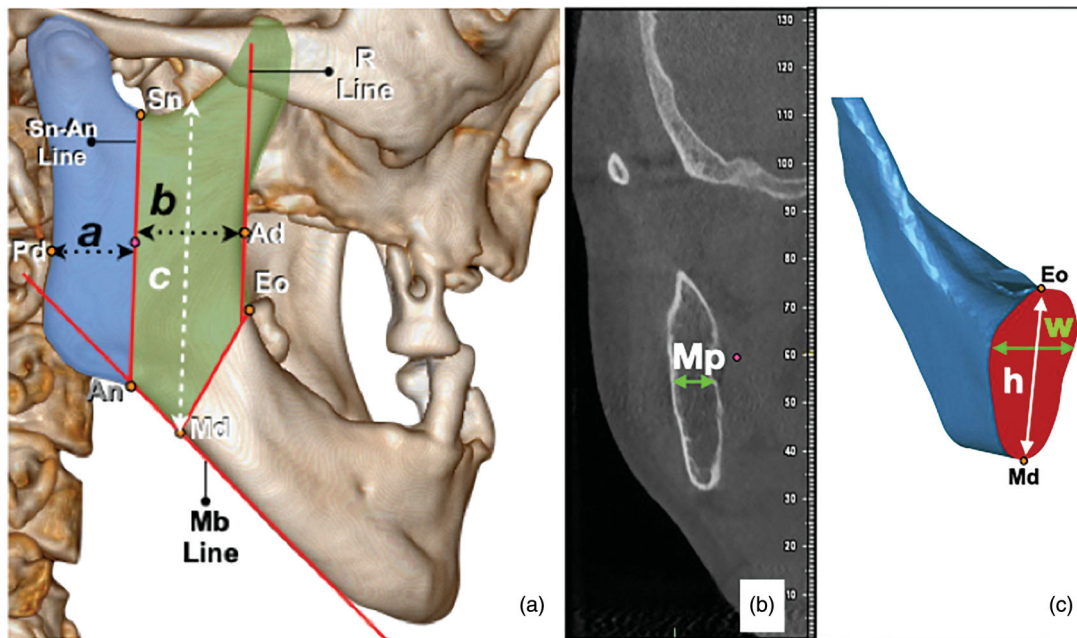


Figure 1. Picture on the left (a): the reference points and lines were marked, *a* and *b* indicates the smallest width of the posterior and anterior ramus respectively, *c* indicates the longest length of the planned anterior ramus graft. Picture in the middle (b): *Mp* is the width of the ramus bone at the mid-point of *Sn-An* Line. Picture on the right (c): the cross-sectional area of *Eo-Md* was marked red (x). The tallest and widest part of the cross section were also measured as *h* and *w*, respectively.

Table 1. Reference points and lines.

Reference	Definition
<i>Sn</i>	The lowest point of the sigmoid notch
<i>An</i>	Highest point of the antegonial notch
<i>Eo</i>	Deepest point on the curvature of the external oblique ridge
<i>Ad</i>	Deepest point on the anterior border of the ramus
<i>Pd</i>	Deepest point on the posterior border of the ramus
<i>Sn-An</i> Line	Line from <i>Sn</i> to <i>An</i> ; delineates the anterior and posterior ramus
<i>Mb</i> Line	Line drawn parallel to the lateral mandibular body, intersecting the <i>Sn-An</i> Line at Point <i>An</i>
<i>R</i> Line	Line parallel to <i>Sn-An</i> line and passing through point <i>Ad</i>
<i>Md</i>	Point where the line drawn from <i>Eo</i> crosses with <i>Mb</i> Line
<i>a</i>	Distance from <i>Sn</i> to <i>An</i>
<i>b</i>	Perpendicular distance from <i>Ar</i> to the line <i>Sn-An</i> .
<i>c</i>	Length of <i>L</i> Line which crosses through the ramus
<i>Mp</i>	Width of the ramus at the mid-point of <i>Sn-An</i> Line
<i>h</i>	Length of the tallest part of the <i>Eo-Md</i> cross section
<i>w</i>	Length of the widest part of the <i>Eo-Md</i> cross section
<i>x</i>	Cross-sectional area of <i>Eo-Md</i>

- v. Has an existing Computed Tomography (CT) scans of the maxilla-mandibular region

Fine cut CT and 3D-reconstructed images were retrieved from the radiology database. Selected images were anonymised. The reference points and lines were first marked on the images (Figure 1 and Table 1): The lowest point of the sigmoid notch (*Sn*), the highest point of the antegonial notch (*An*), the deepest point of the curvature along the external oblique ridge (*Eo*), the deepest point on the anterior border of the ramus (*Ad*) and the deepest point on the posterior border of the ramus (*Pd*).

The following lines were drawn: *Sn-An* Line - Line drawn from *Sn* to *An* which delineates the anterior and posterior ramus; *Mb* Line - Line drawn parallel to the inferior border of the mandible; *R* Line - Line parallel to *Sn-An* line was drawn passing through *Ad*. The ramus was arbitrarily delineated from the mandible body by a line from the point *Eo*, at 150 degrees from the *R* line. At where this line crosses *Mb* line was designated as Point *Md*.

The anterior-posterior length of the anterior and posterior ramus were measured by the perpendicular distance from *Sn-An* Line to *Ad* and *Pd* respectively (*a* and *b*). A line was drawn from point *md* to the sigmoid notch. This line was parallel to the *Sn-An* Line and the length indicates *c*. The cross-section (Bucco-lingual) width of the ramus at the midpoint of *Sn-An* line was also measured (*Mp*). The cross-section area of *Eo-Md* (*x*) was measured using Geomagic Studio 12 (3D systems, South Carolina). Using the same software, the tallest and widest length of the cross section were measured as *h* and *w* respectively.

All measurements were recorded in millimetres (mm). The steps were then repeated again on the contra-lateral side. 2 blinded examiners DY and JH, were involved in the marking of the reference points and measurement of the distances. Inter-examiner calibration was done to ensure 90% agreement in measurements.

2.2. Statistical analysis

Statistical analysis was conducted with SPSS Version 13 software. The significance of the laterality (left or right) to the measurements of *a*, *b*, *c*, *Mp*, *x*, *h* and *w* were analysed with Student's *t* test. Values were considered to be statistically significant when $p < 0.05$.

3. Results

3.1. Anatomical measurements of *a*, *b*, *c*, *Mp*, *x*, *h* and *w*

A total of 80 mandibular rami from 40 subjects were involved in the analysis. The mean age of the subjects was 68 years old. The mean length of *a*, *b* and *c* were 17.3 ± 1.8 mm, 15.9 ± 1.2 mm, 54.6 ± 3.8 mm respectively, while the mean width of *Mp* is 9.8 ± 1.1 mm. Mean cross section area of *Eo-Md* (*x*) was 326.7 ± 67.8 mm². The average length of *h* and *w* were found to be 26.5 ± 3.2 mm and 15.6 ± 2.1 mm respectively. For all measurements, there were no significant difference between the left and right side of the mandible ($p < 0.05$).

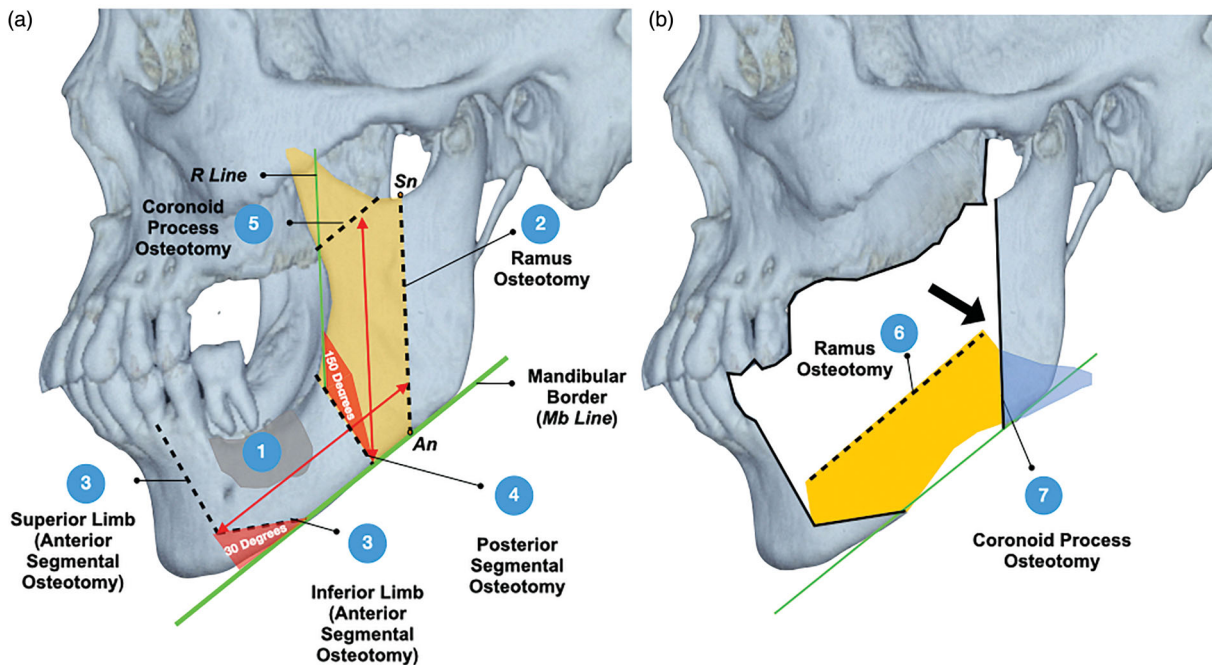


Figure 2. Top picture (a): design of osteotomy; bottom picture (b): rotation of graft. The grey area shows the pathological defect marked with reference to the CT scans. The yellow area indicates the anterior ramus graft. The blue area indicates the remnant coronoid process after the osteotomy. The green lines are the reference lines (*Mb Line* and *R Line*). The black dotted lines are the designed osteotomy lines. The black arrows indicate area of deficiency which can be filled by the remnant coronoid process.

3.2. Digitally designed anterior ramus bone graft

With the study results, we devised a sequence of steps to design the segmental resection and bone graft harvest (Figure 2).

1. Mark the pathological defect on the simulated 3D model with reference to the CT images
2. Ramus Osteotomy: Design the osteotomy from the lowest point of the sigmoid notch to the antegonial notch (Sn-An Line)
3. Anterior segmental osteotomies: The anterior osteotomy consists of two limbs or planes. The inferior limb was X degrees from the border of the mandible (i.e. 30 degrees from *Mb Line*). The superior limb was continuous from the inferior line and the length of each limb should be adjusted till an adequate safety margin can be achieved at all points.
4. Posterior Segmental Osteotomy: The posterior segmental osteotomy was drawn at 180-X degrees to the anterior border of the ramus (i.e. 150 degrees from *R Line*) The osteotomy should be kept at least 1cm away from the pathological defect.
5. Coronoid Process Osteotomy: The distance from the anterior segmental osteotomies to the ramus osteotomy determines the height of coronoid process osteotomy. The angle of the osteotomy was parallel to the border of the mandible (*Mb Line*).
6. Graft Rotation: The graft was then flipped along its long axis (Medial surface rotated to face laterally) and rotated to fit into the defect. The bone surface from the ramus osteotomy should face occlusal, while the bone surface from the coronoid osteotomy should contact the remaining posterior ramus. Alternatively, the graft rotation can be simulated first and the coronoid osteotomy can be determined by the area of overlap.
7. The remnant coronoid process can be used to fill up deficient areas at the anterior and posterior portions of the graft.

3.2.1. Clinical application

Our centre has successfully applied this novel reconstructive approach into our clinical practice. Six patients have underwent simultaneous resection and reconstruction with an anterior ramus bone graft. The period of follow-up ranges from 1 to 2 years. The profile of the patients are summarised in Table 2.

We illustrated the clinical application using one of our cases. The patient was a 68 year old Chinese gentleman who underwent mandibular reconstruction using this method. In July 2018, he was diagnosed with a left mandibular gingival squamous cell carcinoma. Although a marginal mandibulectomy was adequate to clear the disease, a segmental resection was more appropriate in view of his atrophic mandible. Due to the laborious nature of his occupation, the patient refused any form of tissue harvest from his limbs. In order to circumvent the need for extra-oral bone harvest, reduce treatment cost and to reconstruct the mandibular bone continuity, we offered the option of an anterior ramus bone graft to reconstruct the mandible. He was counselled on the advantages and disadvantages of this procedure. Most importantly, we emphasized that the ideal option for oncological cases would be a vascularised bone graft as free bone graft are prone to failure if radiotherapy was deemed to be necessary post-operatively. However, the patient was insistent on not having any operations on his limbs.

3.2.2. Virtual surgical planning and 3D printing

Virtual Surgical Planning (VSP) was done using Proplan CMF 2.0 Software (Materialise, Belgium). The principles of the geometric design was applied on the planning. The fit of the anterior ramus graft was also simulated. Area of deficiency was noted be mainly at the interface between the coronoid osteotomy site and the posterior ramus (Figure 3). Surgical cutting guides were fabricated so as to ensure accurate angulation of the osteotomies. A reconstruction plate was bent on a printed 3D model of the pre-operative mandible. The same model was cut following the surgical

Table 2. Clinical application.

Age/Gender	Duration of reconstruction/ total surgery time (min)	Measurements (mm)				Histopathological results	Follow up period/ recurrence/complications
		DL	Sn	Mp	b		
70/M	30/150	59.5	64.5	16.5	10.5	Highly differentiated SCC. Negative margins No lymph node involvement	1.5 Years/ No recurrence/ Nil complications
69/F	25/166	51.3	60.0	14.1	10.5	Highly differentiated SCC. Negative margins No lymph node involvement	1 Year/ No recurrence/ Nil complications
68/M	20/150	54.2	61.25	21.3	7.2	Highly differentiated SCC. Negative margins No lymph node involvement	2 Years/ No recurrence/ Nil complications
75/F	35/130	52.5	57.1	15.30	10.2	Highly differentiated SCC. Negative margins No lymph node involvement	1 Year/ No recurrence/ Nil complications
71/M	25/165	52.9	58.2	18.60	8.40	Highly differentiated SCC. Negative margins No lymph node involvement	1 Year/ No recurrence/ Nil complications
63/M	25/145	56.3	65.1	18	10.2	Highly differentiated SCC. Negative margins No lymph node involvement	2 Years/ No recurrence/ Nil complications

M: male, F: female; DL: defect length; Sn: lowest point of the sigmoid notch, Mp: Mp is the width of the ramus bone at the mid-point of Sn-An line; b: perpendicular distance from Ar to the line Sn-An. SCC: squamous cell carcinoma.

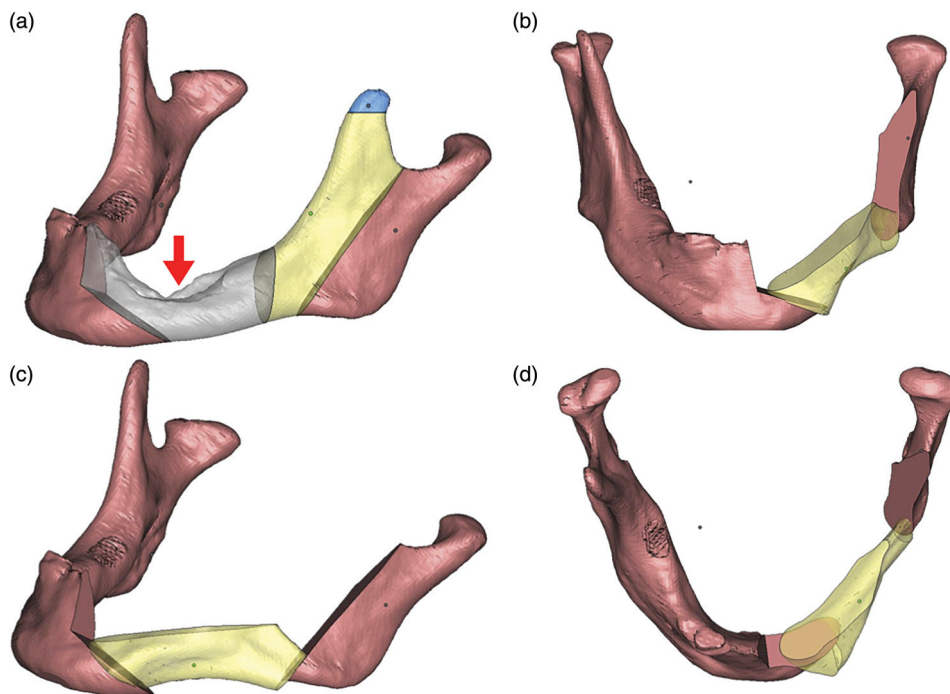


Figure 3. The upper left picture (a) shows the 3D simulation of the unoperated mandible. Pictures (b–d) demonstrates the rotation of the graft. Gray – area to be resected; yellow – anterior ramus graft; blue – remnant coronoid bone; pink – remaining native bone. The red arrow points to the pathological defect.

guides and the fit of the reconstruction plate and the anterior ramus graft was tested (Figure 4).

3.2.3. Surgical procedure

In early August 2018, the patient was admitted for his treatment under general anaesthesia (Figures 5 and 6). The total surgery time was 2.5 h and the reconstruction process only required 20 min. Blood loss was minimal at 100 ml. The post-operative recovery was uneventful, and the patient was discharged 1 week after the surgery. The patient was reviewed every 3 months. After 1 year, there were no signs of recurrence. Radiographic investigations showed bony bridge formation between the graft and native bone. The bone scans also suggest that the grafted bone is viable (Figures 7–9). The patient remains satisfied with the

outcome of the surgery and was able to return to his previous occupation. Figure 10 shows the another case (left mandibular gingival SCC) which also underwent reconstruction of mandible by anterior ramus bone graft.

4. Discussion

The anatomical measurements of the ramus have shown that it is an appropriate site for harvesting bone grafts for the reconstruction of lateral segmental mandibular defects. While there are previous studies in the literature on the use of ramus grafts, these are mainly limited to smaller harvests intended for alveolar bone reconstruction. The use of an intra-oral graft allows the patient to be mobilised earlier by avoiding a separate surgery on the limbs,

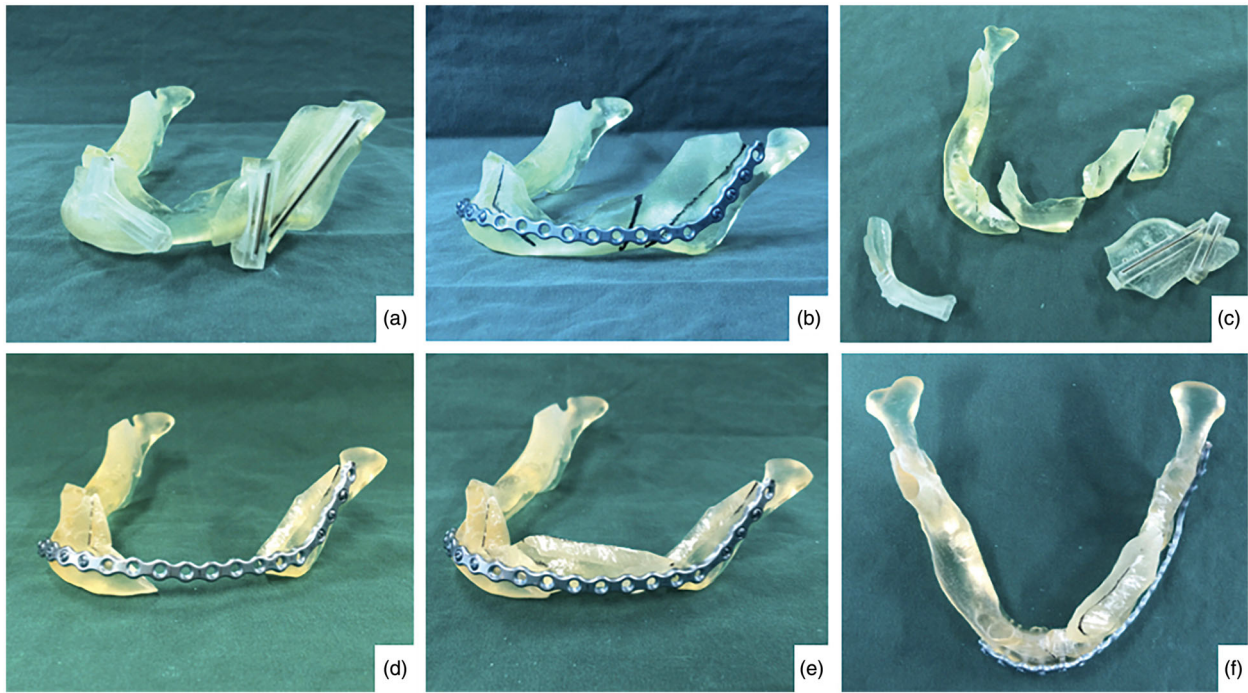


Figure 4. Picture on the upper left corner (a), fitting of the surgical guides; (b) pre-bending of reconstruction plate according to the contour of the 3D printed pre-operative mandible; (c) the 3D printed mandible was cut according to the guides; (d) temporary fixation of the reconstruction plate to the mandible; (e and f) fitting of the anterior ramus graft.

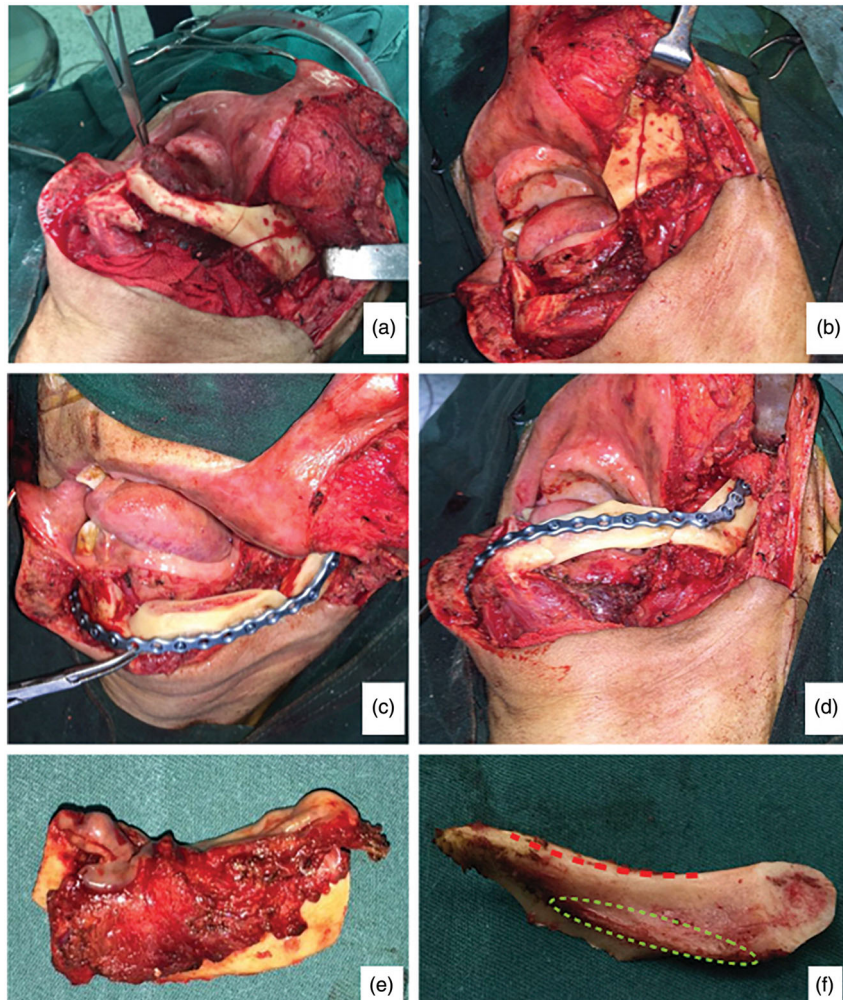


Figure 5. (a) Osteotomy lines; (b) the mandibular segmental defect; (c and d) superior and inferior view of reconstructed mandible; (e) Resected pathology; (f) the red dashed line demonstrate the natural curvature of the anterior border of the ramus – upon rotation, this will form inferior border of the reconstructed mandible. The internal oblique ridge is marked within a green dashed circle.

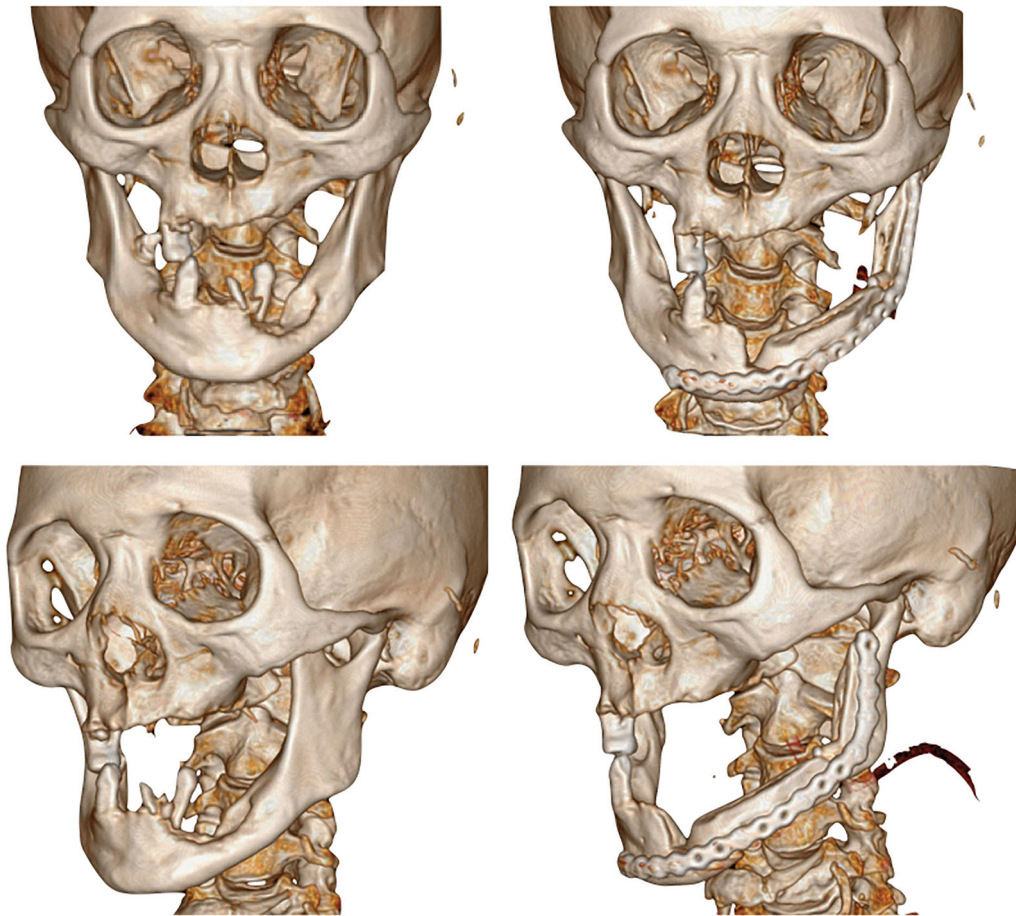


Figure 6. Pre-operative and post-operative computed tomographies (3D reconstructed).



Figure 7. Intra-oral and extra-oral photographs (taken after 12 months post-operatively).

and thus reduces the chance of developing bed sores and venous thrombosis. These outcomes may be beneficial to elderly patients. We have successfully applied this approach in 6 elderly patients (Age ranged from 63 to 70). The surgical duration lasted between 130 and 166 min. Of which, the reconstruction time lasted only 20–35 min. The short surgery time was facilitated by the use of the surgical guides and pre-bent reconstruction plates. With appropriate planning, minimal to no adjustments were required, therefore, reducing both the surgical stress and duration. No complications occurred in any of the 6 patients. Follow ups of 1–2 years did not reveal any signs of graft infection, graft failure or recurrence. All patients remained satisfied with outcomes. We attributed the outcomes to proper case selection, with the criteria as listed in [Table 3](#). Apart from primary closure, it is also crucial to

instill proper oral hygiene and limit functional activity to prevent wound breakdown.

The curvature of the anterior border of the ramus matches well to the inferior border of the mandible. Therefore after the graft rotation, the curvature and the continuity of the mandible can be recreated. Apart from the morphology, the quantity of the graft is equally important. The cross-section area, width and height of the anterior ramus (x , h , and w) are comparable to the fibula and anterior iliac crest bone graft [17,18]. These dimensions are crucial because the graft must be big enough to tolerate masticatory stresses and provide enough surface area to ensure good contact with the native bone [19]. The remaining posterior ramus segment must also be sufficiently thick to support the functional of the mandible and to provide sufficient space for fixation of a reconstructive plate. In this

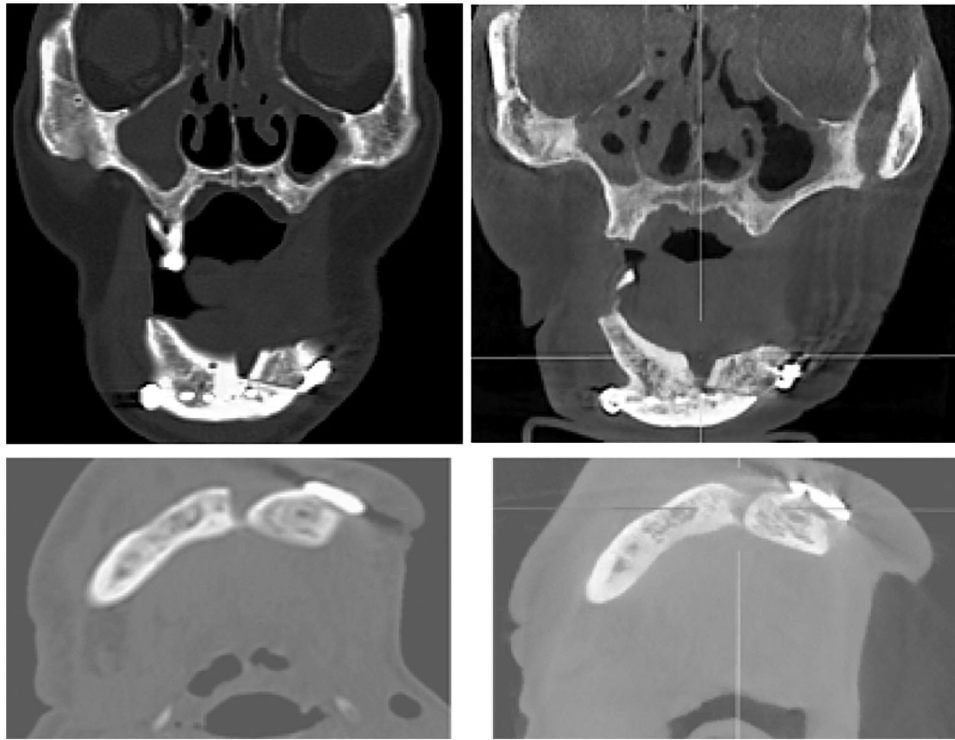


Figure 8. Comparison between the postoperative computed tomographies taken after 1 month and 12 months respectively. Note the radiopaque bone bridge between the grafted bone and the native bone.

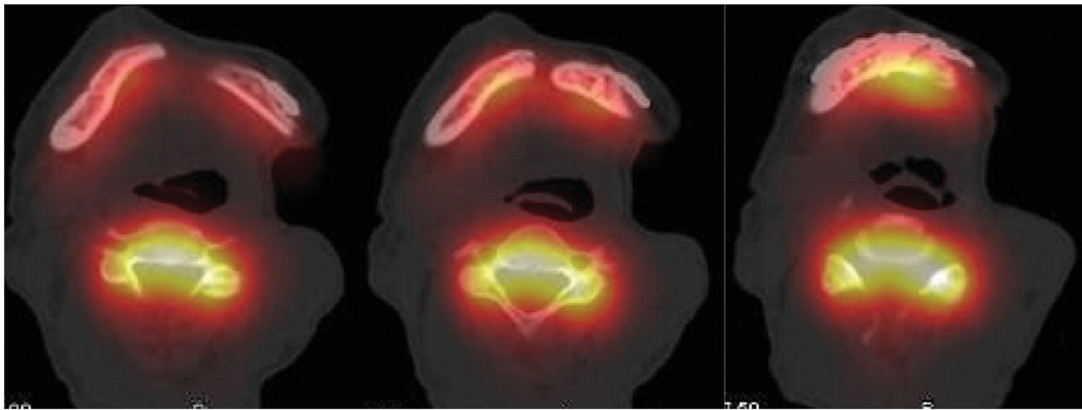


Figure 9. Bone scan taken 12 months post-operatively indicates the viability of the grafted bone.

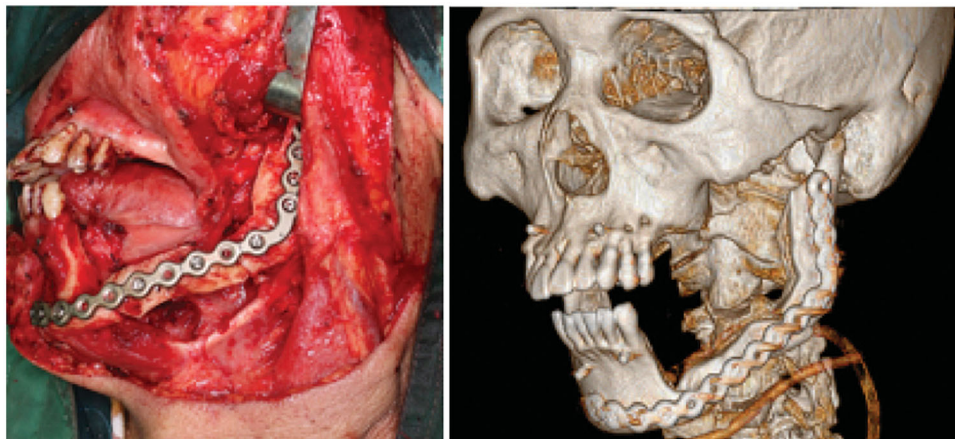


Figure 10. Representative images of another case. The picture on the left shows the intra-operative clinical photos while the picture on right shows the post-operative CT Scan.

Table 3. Proposed criteria for case selection.

Criteria that must be fulfilled	<ol style="list-style-type: none"> 1. Pathology of the mandible body requiring a segmental mandibulectomy (<6 cm) that does not cross the symphyseal region 2. Sufficient mucosa or soft tissue for primary closure after resection (Except if using locoregional soft tissue flaps concurrently) 3. No history of pathologies or surgeries in the ipsilateral ramus 4. The patient has not been irradiated in the head and neck region 5. Post-operative radiotherapy not expected or indicated
One of the following criteria must be fulfilled	<ol style="list-style-type: none"> 1. Systematic medical conditions that makes long surgical duration risky and unfavourable i.e. cardiac diseases 2. Local conditions that contra-indicates extra-oral autogenous bone harvest i.e. venous stenosis or history of limb fracture 3. Patients who are unwilling to have a second surgical site or to have surgery on their limbs

study, the posterior ramus was measured to be 17.3 mm. This is comparable to the thickness of a fibula bone graft, which was reported to be approximately 15 mm thick [20]. However, it is important to note that unlike the fibula bone, the thickness of the posterior ramus is not consistent throughout its entire length. Furthermore, functional stresses are also not equally distributed and tends to greatest at the condylar region [21]. Therefore, it is also important to not reduce the dimensions of the condylar region by keeping the ramus osteotomy within the Sn-An Line. Removal of the coronoid and detachment of the temporalis muscle as part of the harvesting procedure will also help to reduce functional load on the remaining ramus.

The ideal goal of mandibular reconstruction would include oral rehabilitation with implant-supported dental prostheses. The mean mid-ramus width and anterior-posterior length of the anterior ramus were measured to be 9.8 and 15.9 mm, respectively. This would allow for the placement of wide diameter dental implants of 10 mm in length. The harvested anterior ramus also offers a good balance of cortical and cancellous bone, which provides for adequate implant stability and vascularity for osseointegration [22,23]. The intramembranous lineage of the ramus may provide several advantages over autogenous graft of endochondral origin. Intramembranous grafts have been shown to result in higher rates of revascularisation and healing. Furthermore, the rate of resorption of these grafts were found to be much slower when compared to bone from endochondral origin [24,25]. This is especially important as the dental implants are usually placed 6 months later. However, the placement in this graft will require further validation.

There are several caveats to this approach. Firstly, the ramus of the mandible was halved and its effect on the masticatory strength remains to be investigated. There may also be concerns whether the remaining ramus will be prone to fracture. However, given the experience from fibula bone grafts, it was deemed to be unlikely. Secondly, despite that the grafts were taken from the same surgical site of the resection, they were still non-vascularised bone grafts. In the absence of a pedicle, non-vascularised grafts are at greater risks of resorption, necrosis and infection. In view of this, vascularised flaps are usually considered in patients who are prone to infections and those who had or will undergo radiotherapy. These are typically patients with oncologic disease. While free bone graft techniques are mainly used in benign pathologies, we have managed to show successful use of this graft in oncologic patients. In order to reduce the likelihood of complications, criteria indicated in Table 3 should be fulfilled, i.e. the length of defect to be reconstructed should not exceed more than 6 cm [12]. There are also potential for the anterior ramus graft to be vascularised by keeping a significant amount of periosteum and muscles attached (i.e. temporalis or medial pterygoid muscles).

5. Conclusion

There are clinical situations where an anterior ramus bone graft may be preferred or when the most ideal treatment is not

accepted by the patient i.e. for elderly patients where long surgeries are not recommended or who decline harvesting bone from a separate site. In these situations, this novel approach will be a viable alternative. The use of digital technology to plan the surgery will allow the potential of the graft to be maximized. Further investigations on the validation of the use of dental implants in this graft will be useful. (3589 words)

Disclosure statement

No potential conflict of interest was reported by the author(s).

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ORCID

Dan Yu  <http://orcid.org/0000-0001-5380-465X>

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