

# Expert Consensus for the Treatment Algorithm for Navigation-assisted Reconstruction of Maxillofacial Deformities

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*Deformities of the maxillofacial region following trauma and ablative surgery are devastating and not uncommon. Reconstruction of such defects is a surgically challenging procedure. Conventionally, reconstruction of dental arch defects lacks preoperative customised planning and relies heavily on the surgeon experience to ensure optimum surgical outcomes. The restoration of the dental arch shape and function has taken precedence after an extensive tumour resection surgery, especially in the current age of technological advancement. Thus, personalised and accurate reconstruction of dental arch defects has become a new goal. Computer-assisted surgery, especially navigation-assisted surgery, has gained popularity of late, in reconstructing deformities and restoring facial symmetry, appearance and function in the maxillofacial region. This technology provides a clearer three-dimensional visualisation of the area of interest and its relationship with the adjacent vital structures. Together with preoperative virtual surgical planning, it allows more specific and accurate osteotomies, thus reducing the ischemia and total operating times substantially. The risk of complications is also minimised whilst improving the final surgical outcomes. The use of the intraoperative navigation system and other computer-assisted surgical techniques during surgery can significantly improve the precision of the reconstruction of dental arch deformities, and achieve personalised and functional reconstructive goals while enhancing the quality of life of patients postoperatively. The Society of Oral and Maxillofacial Surgery, Chinese Stomatological Association provides the present professional perspective and treatment protocol for navigation-guided reconstruction of dental arch defects, to allow standardisation of the technique while promoting its application among oral and maxillofacial surgeons.*

**Key words:** bone remodelling, jaw defect, reconstruction, navigation technique, digital surgery, expert consensus

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Deformities of the maxillofacial region following trauma and ablative surgery are devastating and not uncommon. Reconstruction of such defects is a surgically challenging procedure. Conventionally, the reconstruction of dental arch defects lacks preoperative customised planning and relies heavily on the surgeon experience to ensure optimum surgical outcomes<sup>1</sup>.

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Computer-assisted surgery, especially navigation-assisted surgery, has gained popularity of late in reconstructing deformities and restoring facial symmetry, appearance and function in the maxillofacial region.

This technology provides a clearer three-dimensional (3D) visualisation of the area of interest and its relationship with the adjacent vital structures. With preoperative virtual surgical planning, it allows more specific and accurate osteotomies, thus reducing the ischemia and total operating times substantially. The risk of complications is also minimised whilst improving the final surgical outcomes. The use of the intraoperative navigation system and other computer-assisted surgical techniques during surgery can significantly improve the precision of the reconstruction of dental arch deformities, and achieve personalised and functional reconstructive goals while enhancing the quality of life of patients postoperatively<sup>2-11</sup>.

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## Indications

- Patients who are between the age of 18 and 70 years;
- Unilateral maxillary benign or malignant tumour requiring unilateral subtotal maxillectomy or total maxillectomy;
- Primary mandibular benign or malignant tumour requiring segmental mandibulectomy (with or without resection of the condyle);
- Primary reconstruction of the maxillary defect with free fibular flap (combining customised titanium mesh);

- Primary reconstruction of the mandibular defect with free fibular flap or deep circumflex iliac artery (DCIA) free flap (using customised reconstruction titanium plates);
- No absolute anaesthesiological contraindications.

## Preoperative design

### *Image data acquisition*

A high-resolution spiral computed tomography (CT) scan (thickness  $\leq 1.25$  mm) of the recipient and donor site (both lower limbs or pelvis) in DICOM format should be obtained. The CT scan of the recipient site should include a region from 2 cm superior to the supraorbital rim to the supraclavicular level. A thin occlusal splint should be fabricated preoperatively and worn during the CT scan to maintain the patient's centric occlusion.

### *3D evaluation of tumours*

#### 1. 3D tumour mapping of the maxillary tumour

The patient's diagnostic images should be uploaded into the image guided surgery (IGS) software which allows surgeons to outline the tumour and the critical structures surrounding it (such as internal carotid artery, internal jugular vein and styloid process), producing a 3D visualisation showing the tumour and its relationship with the adjacent important structures<sup>12,13</sup> (Fig 1).

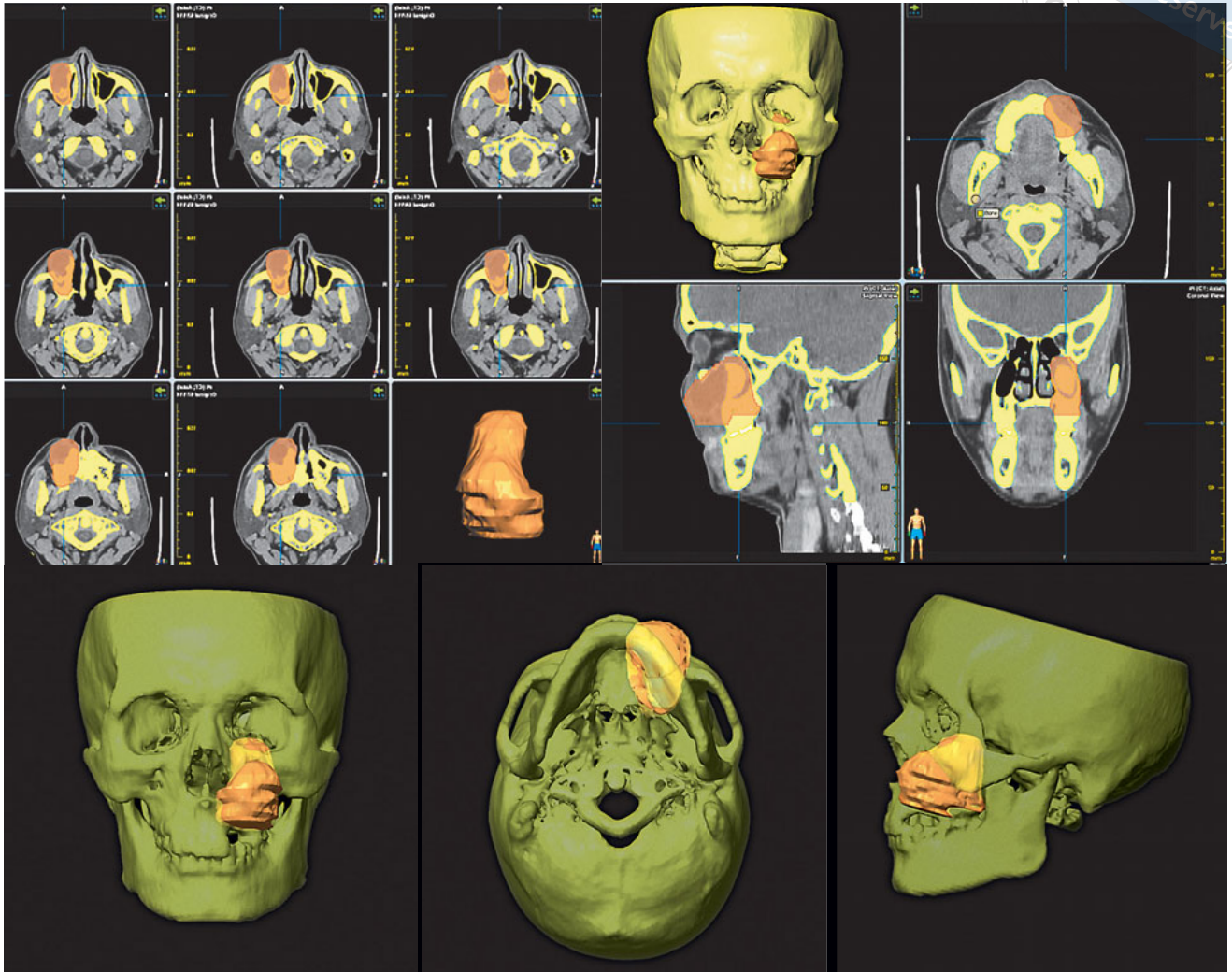
#### 2. Assessment of the tumour margins

An accurate preoperative assessment of the mandibular tumour can be performed through thorough clinical examination and using the patient's diagnostic imaging such as an orthopantomogram (OPG) and a CT scan.

### *Virtual simulation of the resection*

#### 1. Virtual maxillectomy

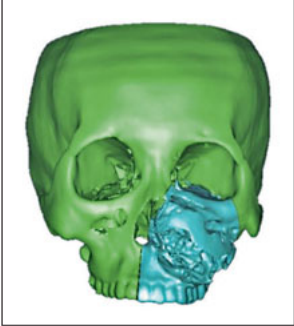
The CT scan should first be uploaded to virtual surgical planning software. The manual segmentation of the skull CT dataset should be performed to generate both maxilla, mandible and other relevant anatomical structures. Based on the 3D tumour mapping, virtual osteotomies should be planned and customised for each patient. After completion of the virtual osteotomies, a virtual model of the maxillary defect should be acquired<sup>14</sup> (Fig 2).



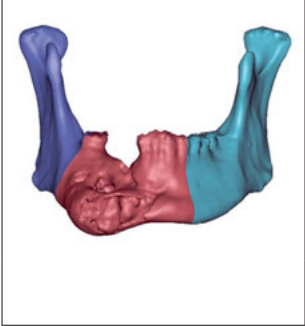
**Fig 1** Using the software, precise tumour mapping can be performed, producing a 3D model showing the tumour and its relationship with the adjacent important structures.

2. Virtual simulation of segmental mandibulectomy

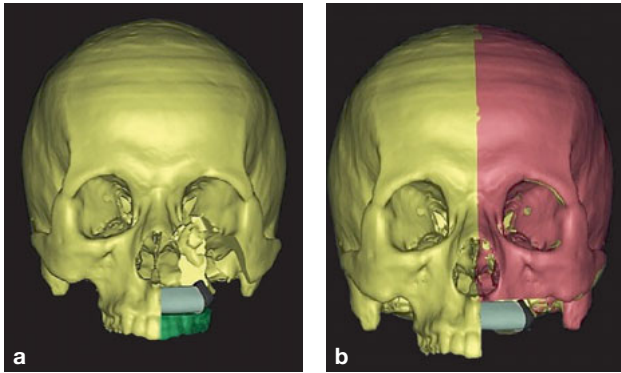
The CT scan should first be uploaded to virtual surgical planning software. The manual segmentation of the skull CT dataset can be performed to generate both maxilla, mandible and the relevant anatomical structures. Based on the 3D tumour mapping, virtual osteotomies should be planned and personalised for each patient<sup>15</sup> (Fig 3). After completion of the virtual osteotomies, a virtual model of the mandibular defect can be acquired. Subsequently, cutting guides should be designed to improve the accuracy of the osteotomy intraoperatively.



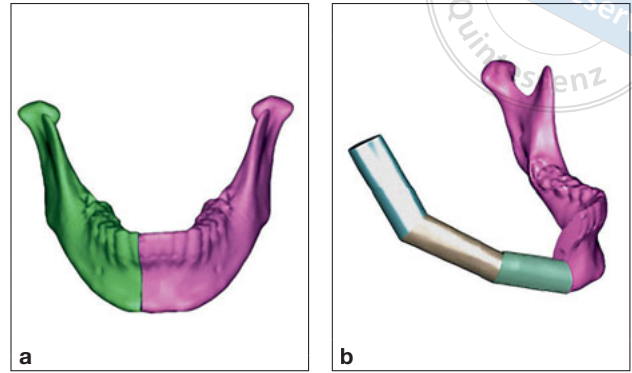
**Fig 2** Virtual simulation of the maxillary tumour resection.



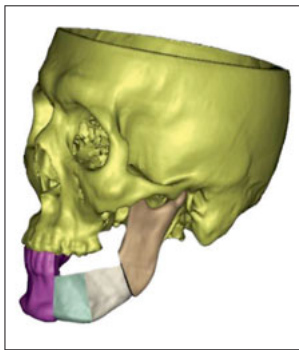
**Fig 3** Virtual simulation of tumour resection and segmental mandibulectomy.



**Fig 4 (a)** Virtual reconstruction of the maxillary alveolar process with fibula, and **(b)** restoring the outline of the affected maxilla using the mirroring technique.



**Fig 5 (a) and (b)** Virtual reconstruction of the mandibular defect using the mirroring technique.



**Fig 6** Virtual simulation of the reconstruction of the mandibular defect with iliac bone.

*Virtual simulation of the tumour resection and segmental mandibulectomy*

1. Virtual simulation of the reconstruction of the dental arch defects

The CT data of the lower limbs should be uploaded to the software and the segmentation should be performed to create the fibula needed for reconstruction. Virtual reconstruction with the segmented fibula should then be conducted and designed according to the dental arch shape and occlusal relationship<sup>14</sup>.

If the defect involves the anterior wall of the maxillary sinus, the orbital floor and the zygomatic bone, the mirroring technique should be performed to mirror the healthy side to the affected side, restoring the outline and shape of the affected maxilla, orbital floor and zygomatic bone<sup>16</sup>.

To obtain an ideal virtual maxillary reconstruction, the maxillary defect model, the mirrored image and the fibula data should be combined, and the design should be adjusted accordingly in each patient (Fig 4).

2. Reconstruction of a mandibular defect with a virtual free fibular flap

The CT data of the lower limbs should be uploaded to the software and the segmentation performed to create the fibula needed for reconstruction. The virtual reconstruction with the segmented fibula can then be conducted and designed according to the dental arch shape and occlusal relationship (Fig 5).

If the tumour has breached the inferior border of the mandible or has caused significant buccolingual expansion, the mirroring technique should be performed to mirror the healthy side to the affected side, restoring the outline and shape of the affected mandible.

In order to achieve an ideal virtual mandibular reconstruction, the mandibular defect model, the mirrored image and the fibula data should be combined, and the design should be modified accordingly<sup>15</sup>.

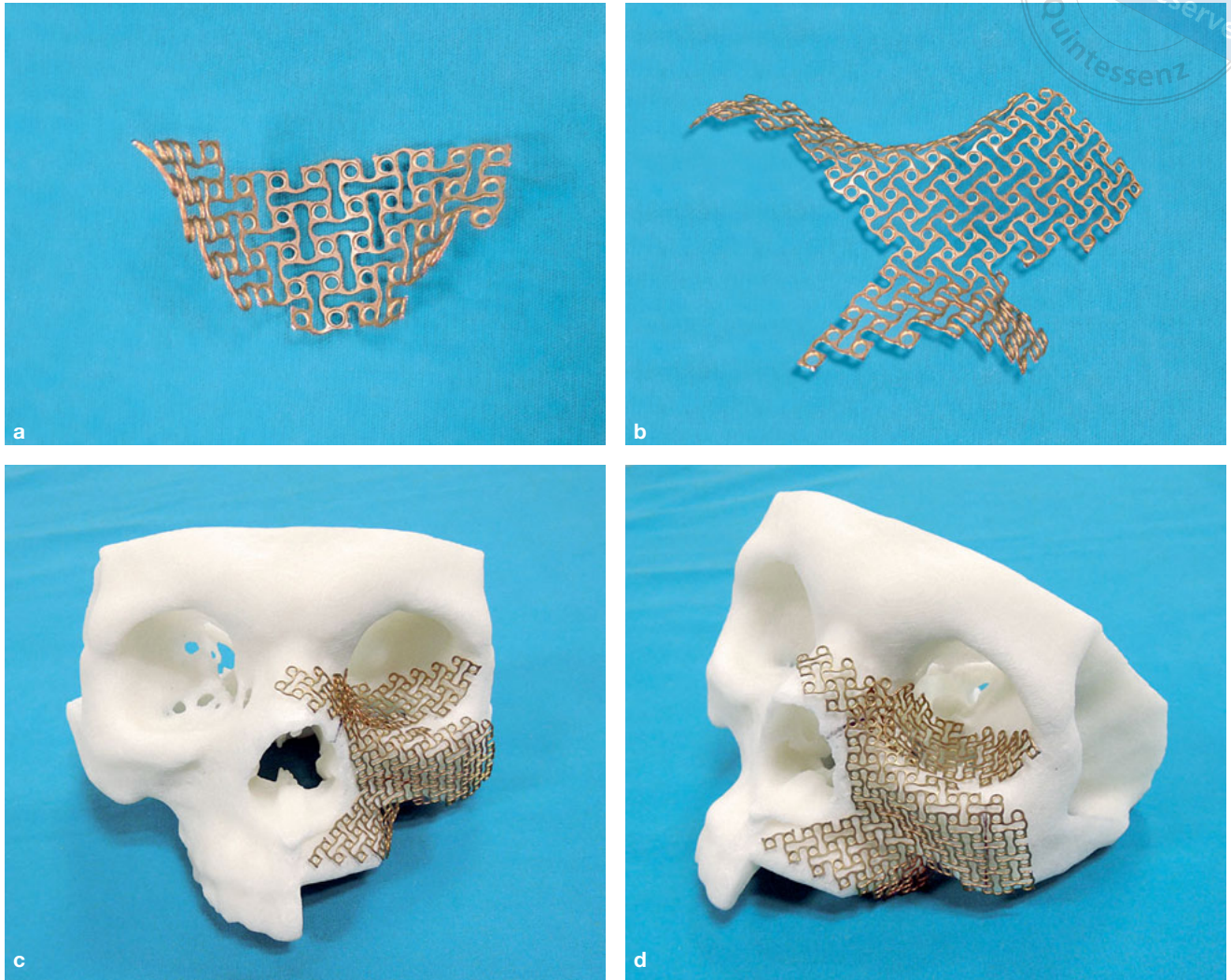
3. Reconstruction of a mandibular defect with a virtual free ilium flap

The CT data of the pelvis should be uploaded to the software and the segmentation performed to generate the iliac bone needed for reconstruction. The virtual reconstruction with the segmented iliac bone should be conducted and designed according to the dental arch shape and occlusal relationship<sup>17,18</sup> (Fig 6).

*3D printed cast and patient-specific titanium mesh or titanium plate*

1. 3D maxillary model and customised titanium mesh

After virtual surgery, the desired reconstructed maxillary model data should be exported in STL format and



**Fig 7 (a) to (d)** Three-dimensional printed maxillary cast and pre-contouring of the titanium mesh to produce a customised titanium mesh.

a cast printed using medical grade resin. The titanium mesh (craniomaxillofacial osteosynthesis titanium mesh of 0.6-mm thickness) should be contoured on the printed cast (in this case, to repair the anterior maxilla and orbital floor)<sup>14,16</sup> (Fig 7).

The virtual fibula segments should be placed at their original positions to design fibula cutting guides or templates. By exporting the virtual fibula segments in STL format, the cutting guides or templates can then be designed and printed.

## 2. Virtual reconstruction of the mandibular defect with a fibula flap

After virtual surgery, the desired reconstructed mandibular model data can be exported in STL format and a cast

printed using medical grade resin. The mandible cast (with fibula segments) allows modelling and shaping of the fibula flap intraoperatively<sup>15</sup>.

## 3. Virtual reconstruction of the mandibular defect with a deep circumflex iliac artery free flap and a personalised reconstruction titanium plate

After virtual surgery, the desired reconstructed mandibular model data can be exported in STL format and a cast printed using medical grade resin. The mandibular cast (with iliac bone segments) allows pre-bending of the reconstruction titanium plate (thickness of 2.4 mm) to fixate the mandible and to provide a foundation of the mandibular outline. A CT scan is then performed on the printed cast with the reconstruction titanium plate.



**Fig 8** Three-dimensional printed mandibular cast and pre-bending of the reconstruction titanium plate to produce a customised reconstruction titanium plate.

The DICOM data of the reconstruction plate should be extracted and used intraoperatively to ensure an accurate and precise position of the reconstruction titanium plate under navigation-assisted surgery<sup>17,18</sup> (Fig 8).

The virtual iliac bone segments should be placed at their original positions to design the iliac bone cutting guides or templates. By exporting the virtual iliac bone segments in STL format, the cutting guides or templates can be printed into 3D casts.

## Surgery

### Patient registration

The patient's CT data should first be uploaded to the navigation workstation. Under general anaesthesia, a small incision of approximately 1 cm should be made on the scalp, exposing the cranium. A skull post should be applied to the cranium with a rigid fixation screw. The dynamic reference frame is then connected to the skull post. The rigid fixation screw should be placed securely whilst avoiding the sutures, as it maintains a stable relationship between the patient and the dynamic reference frame during registration and the surgical procedure. The skin surface registration can be performed by moving a registration laser pointer over the skin surface. Other registration techniques include the registration of the anatomical landmarks. The registration techniques may differ from one navigation system to another<sup>19</sup>.

### Tumour resection under navigation-assisted surgery

#### 1. Maxillectomy under navigation-assisted surgery

Following adequate exposure of the tumour, the position of each osteotomy line should be located and determined using the navigation probe. The osteotomy is then completed accurately according to the planned osteotomy line<sup>14</sup> (Fig 9).

#### 2. Resection of the mandibular tumour under navigation-assisted surgery

The prefabricated occlusal splint should be placed to maintain the patient's centric occlusion. Each osteotomy line should be determined using the navigation probe, and then marked. The osteotomy should then be completed accurately according to the planned osteotomy line<sup>15</sup>.

Contrary to the maxilla, the stability of the mandible is relatively poor, especially in the absence of a stable occlusion. The cutting guides, therefore, are invaluable in ensuring accurate osteotomies under navigation-assisted surgery.

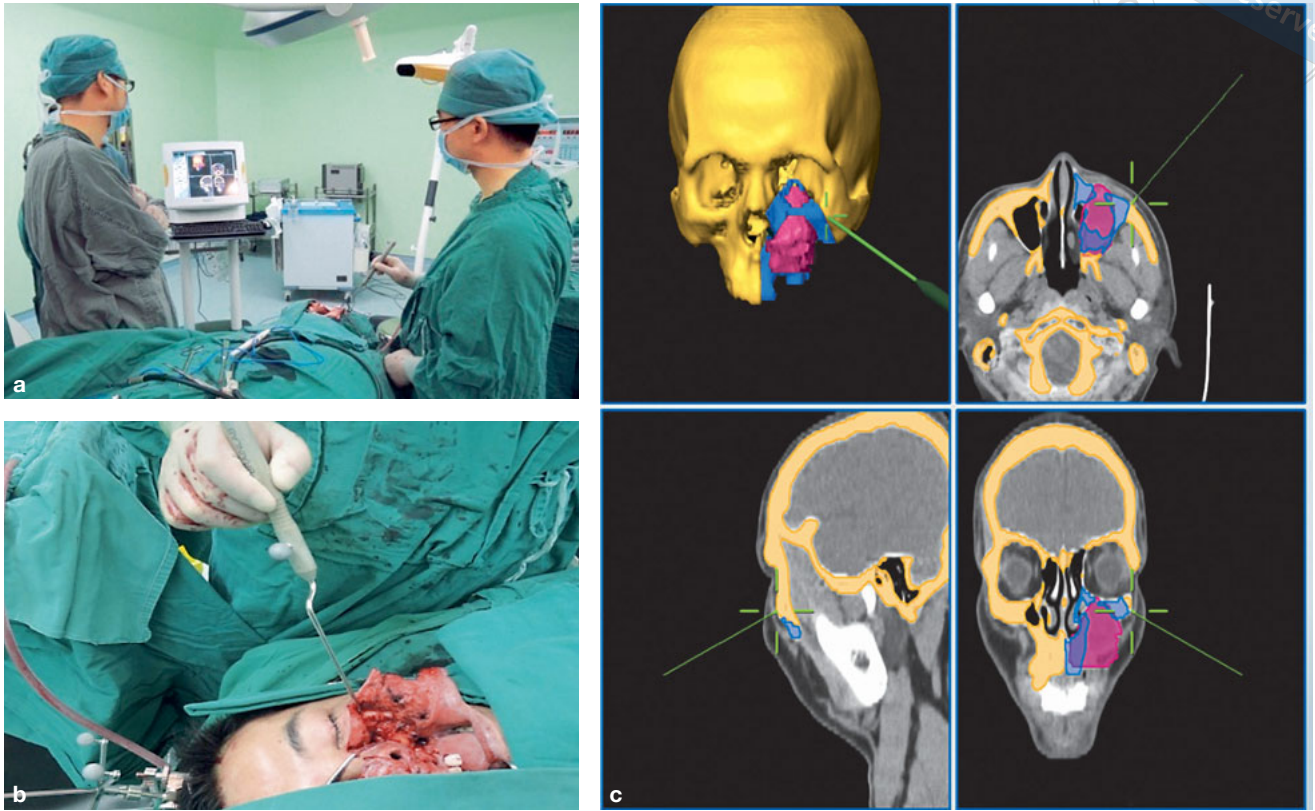
### Navigation-assisted dental arch reconstruction surgery

#### 1. Reconstruction of maxillary defects under navigation-assisted surgery

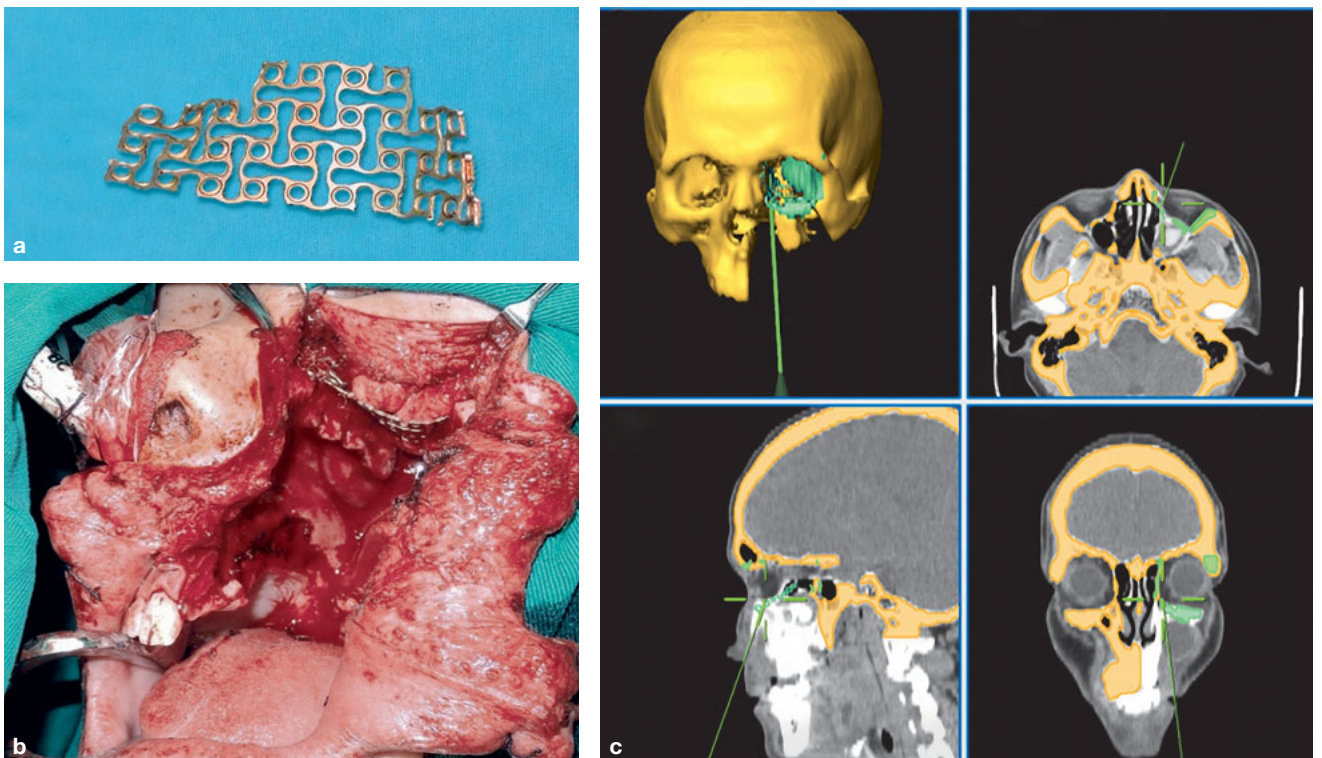
Using intraoperative navigation, the orbital floor can be determined accurately, and the pre-contoured customised titanium mesh can be fixed to repair the orbital floor defect. The position of the titanium mesh should be validated again using intraoperative navigation<sup>14,16</sup> (Fig 10).

The fibula flap should be shaped according to the cutting templates designed preoperatively and transferred to the recipient site. Using the intraoperative navigation system, the position of the fibula segments can be ascertained, mainly by verifying the horizontal and vertical distances and the position of the distal end. The final position of the fibula segments should be as close as possible to the preoperative surgical plan. The position of the fibula segments should be verified once again following the fixation<sup>14</sup> (Fig 11). The pre-contoured titanium mesh should be adjusted and fixed accordingly.

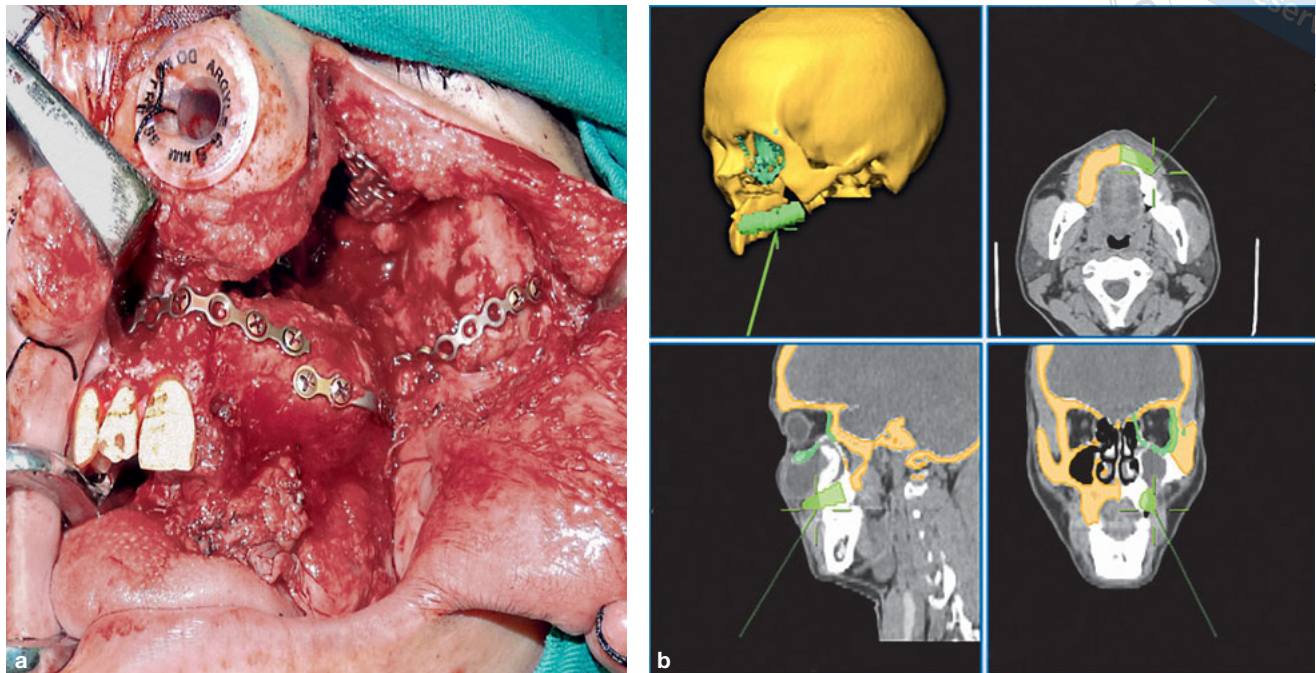
Please note that the reconstruction procedures for a Brown's Class III maxillary defect following total maxillectomy should include the above-described processes, while for a Brown's Class II defect following a



**Fig 9 (a) to (c)** The osteotomy lines can be determined and the tumour resection accurately performed using intraoperative navigation.



**Fig 10 (a) to (c)** Using intraoperative navigation, the position of the titanium mesh can be accurately determined.



**Fig 11 (a) and (b)** Intraoperative navigation allows the precise positioning of the fibula flap and restoring of the maxillary defect.

subtotal maxillectomy, only the reconstruction of the fibula flap may be included.

## 2. Reconstruction of the mandibular defect under navigation-assisted surgery

Following the intermaxillary fixation, the fibula flap can be shaped according to the cutting templates designed preoperatively and transferred to the recipient site. Using the intraoperative navigation system, the position of the fibula segments can be determined, mainly by validating the position of the angle and condyle of the mandible. The final position of the fibula segments should be as close as possible to the preoperative surgical plan. The position of the fibula segments should be verified once again following the fixation<sup>15</sup> (Fig 12).

## 3. Reconstruction of the mandibular defect with a deep circumflex iliac artery flap under navigation-assisted surgery

Following the intermaxillary fixation, the position of the customised reconstruction titanium plate should be confirmed, and the fixation subsequently performed (Fig 13).

The iliac bone flap should be shaped according to the cutting templates designed preoperatively, then

transferred to the recipient site. Using the intraoperative navigation system, the 3D position of the iliac bone segments can be ascertained. The final position of the iliac bone segments should be close to the preoperative surgical plan. The position of the iliac bone segments can be verified once again following the fixation<sup>17,18</sup>.

## Postoperative evaluation

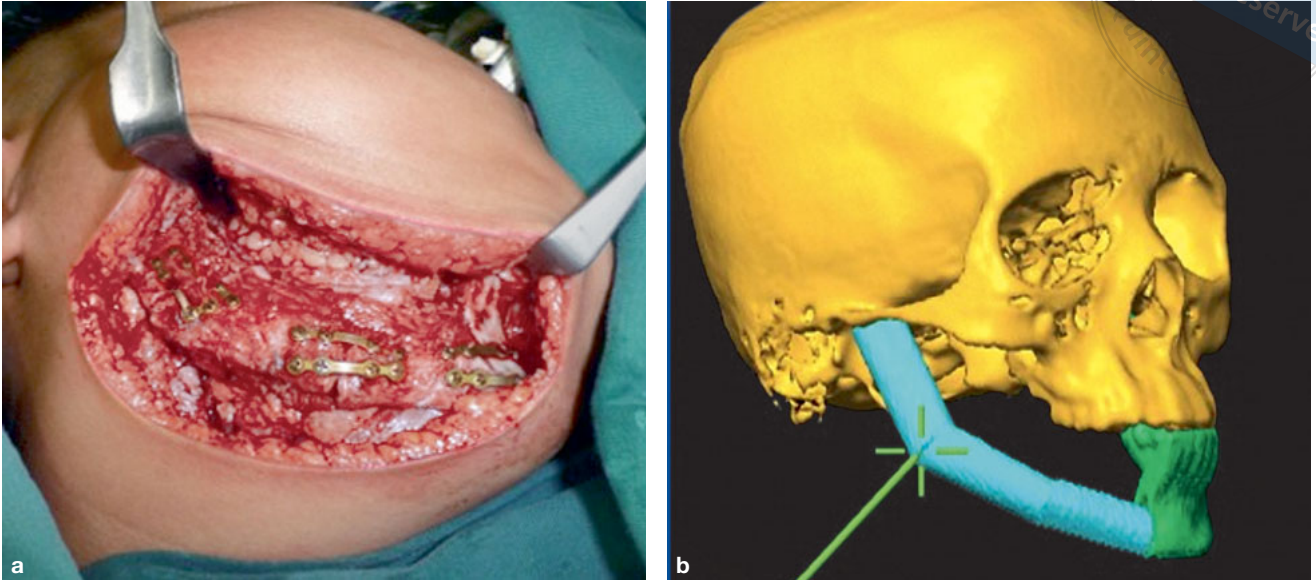
### *Evaluating the accuracy of the navigation-assisted surgery*

A postoperative CT scan can be acquired within a week postoperatively. The 3D model representing the postoperative surgical outcome can be reconstructed, and its STL format should be derived. To perform comparisons and evaluate the accuracy, the postoperative 3D model should be superimposed onto the preoperative virtual surgical plan using manual alignments<sup>14,15</sup> (Fig 14).

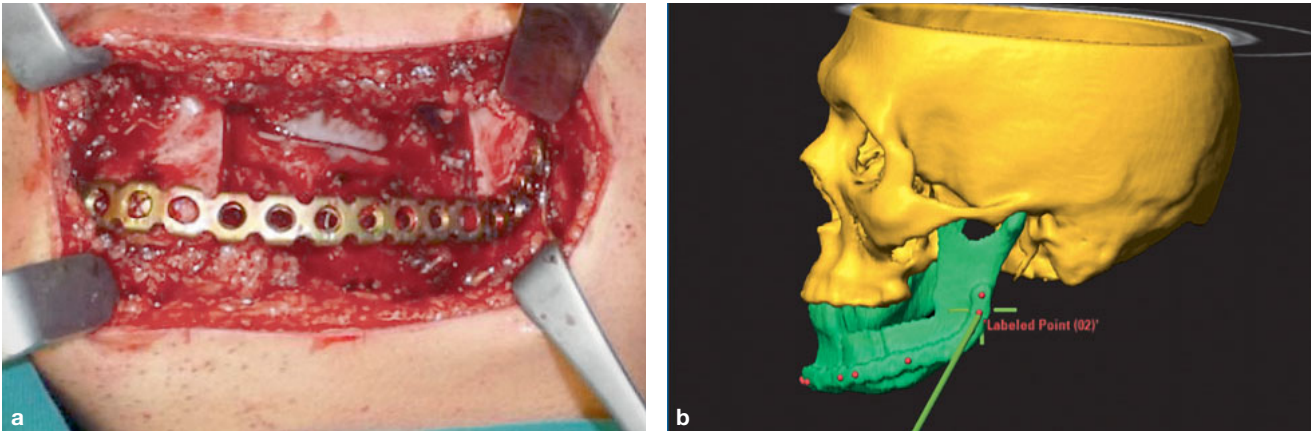
### *Evaluation of the maxillary reconstruction effect*

A postoperative CT scan should be acquired within a week after the surgery. The 3D model representing the postoperative surgical outcome can be reconstructed,

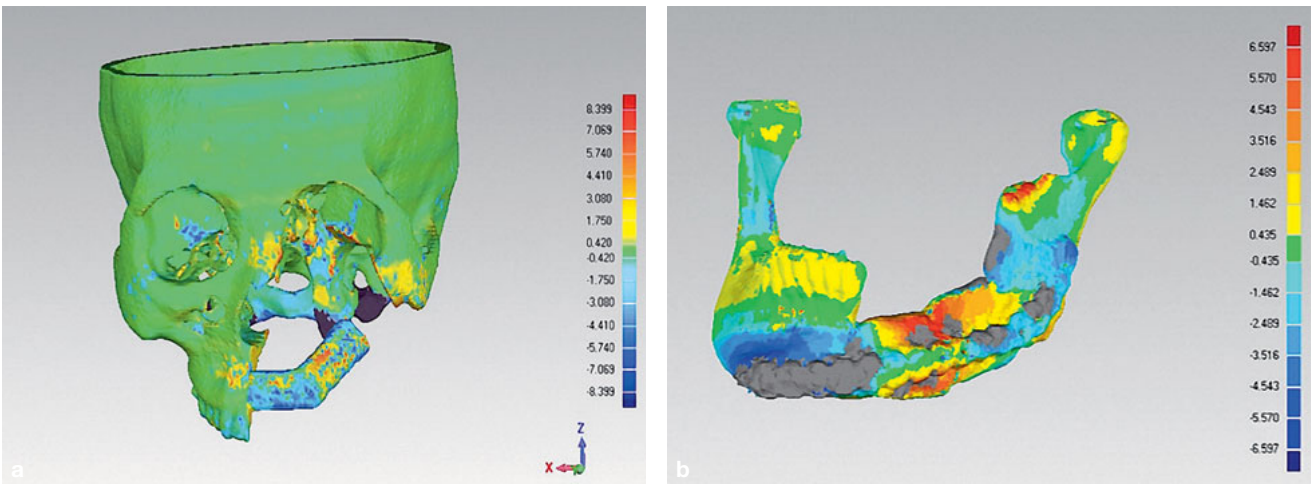




**Fig 12** (a) Intraoperative navigation allows the precise positioning of the fibula flap, and (b) restoring the mandibular defect.



**Fig 13** (a) Precise position of the reconstruction plate, and (b) stable occlusal relationship can be achieved using intraoperative navigation.



**Fig 14** (a) and (b) Heat map chromatographic analysis of the preoperative and postoperative CT scans showing the mean distance. Comparing the actual position of the free flap with the planned one can be accurately achieved.

and the following 3D measurements should be performed:

- Vertical dimension of the fibula: interocclusal distance of the reconstructed region (canine and first molar area).
- Horizontal position of the fibula: the difference in distance between the long axis of the fibula and the long axis of the dental arch.
- Position of the distal end of the fibula: the relationship of the distal end of the fibula with the contralateral alveolus and ipsilateral coronoid process of the mandible<sup>14</sup>.

#### *Evaluation of the mandibular reconstruction effect*

A postoperative CT scan should be acquired within a week after the surgery. The 3D model representing the postoperative surgical outcome can be reconstructed, and the following 3D measurements should be performed:

- Deviation of the condylar position: the difference between the preoperative condylar position and the postoperative reconstructed neo-condyle.
- Deviation of the mandibular angle position: the difference between the preoperative mandibular angle position and postoperative reconstructed mandibular angle position.
- The angulation difference of the mandibular angle: comparing the preoperative and postoperative mandibular angle.
- The changes in mandibular angle width: comparing the distance between bilateral mandibular angle pre- and postoperatively<sup>15</sup>.

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