Mandibular Surgical Navigation: An Innovative Guiding Method

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Abstract: Mandibular osteotomies are usually required to treat craniomaxillofacial disorders. Losses of mandibular continuity result in esthetic and functional deficiency. During the past 30 years, the spread of the computer-assisted surgery techniques, rapid prototyping, and surgical navigation technique has improved the reliability and the outcomes of mandibular resections and reconstructions, by providing realtime feedback to surgeon. Recent studies reported the feasibility and the precision of surgical navigation applied to mandibular surgical resection and reconstruction with fibula flap but none of them describes a method to navigate the jaw allowing its full motility during the operation. To our knowledge, this is the first-time description of such a kind of method to navigate the jaw positioning the dynamic reference frame directly on the mandibular branch to maintain the full mobility of the mandible. The method described in our series has allowed an accurate surgical navigation of the jaw without the need of intermaxillary fixation. This technique could greatly facilitate resection and reconstructive surgical procedures of the jaw while ensuring precision and accuracy. The encouraging results obtained in the present report suggest to further investigate the possibilities of this technique to better define the method and its indications.

Key Words: Computer-aided design, computer aided manufacture, fibula flap, mandibular navigation, mandibular reconstruction, surgical navigation

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Mandibular osteotomies are usually required to treat craniomaxillofacial deformities, including orthognathic surgery, bone benign or malignant neoplasms exeresis, and also for resections in condilar pathology, malformations, dysplasia, trauma, and bone infectious diseases.[1–4]

Integrity of the jaw is required to carry out several complex functions. Mandible ensures support for tongue, lower dentition, floor, and masticatory muscles. Its continuity allows chewing, swallowing, and speaking.[5,6]

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Besides, it cannot be underestimated that it represents the contour of the lower third of the face and ensure airway protection.

Losses of mandibular continuity result in deviation of the mandible toward the pathological side because of the unopposed pull of the remaining muscles of mastication, eventually with limited range of motion when attempting lateral and protrusive movements of the jaw; thus, malocclusion and proprioceptive problems occur.

The computer-assisted surgery (CAS) techniques, which mainly consist of computer-aided design (CAD), computer-aided manufacture (CAM), rapid prototyping (RP),[4,7–9] and surgical navigation technique have contributed during the last 10 years to evolve the precision of this kind of surgery, in the same time simplifying it. Before the spread of this innovative tool, osteotomies were surgeon-depending mode performed. Osteotomic lines were carried out basing on tumor visualization keeping away from the lesion. The same occurred for mandibular reconstructions. Computerized navigation has improved the reliability and the outcomes of mandibular resections and reconstructions, by providing realtime feedback to surgeon.

Recent studies reported the feasibility and the precision of surgical navigation applied to mandibular surgical resection and reconstruction with fibula flap.[3,4,10–13]

In a study by Shan et al,[13] the authors adopted intermaxillary fixation to have the light-reflecting spheres of the dynamic reference frame (DRF) rigidly fixed to the skull, thus allowing the mandible to be navigated. This method does not allow the opening of the mouth making the mandibular resection/reconstruction most difficult and also limiting the surgical applications.

In this technical report, we want to evaluate the feasibility of mandibular surgical navigation by positioning the DRF directly on the mandibular branch, thus allowing mandible motility during the intervention.

Technical Report

Between 2011 and 2015, 4 patients who underwent mandibular resection and reconstruction with free fibula flap were enrolled in our study because they meet the following protocol:

Inclusion criteria:

1. Partial resection of the mandible was indicated.
2. Reconstruction with a fibula graft was possible.
3. The patient could wait 7 to 14 days for a design to be created.
4. Patient agreed to the surgical team using a computer-assisted navigation method.

Exclusion criteria were the following:

1. Operation time had to be controlled because of the general status of the patient.
2. Advanced malignant tumor with a poor prognosis.

A preoperative incisional biopsy was done to obtain a pathological diagnosis. Reconstruction was indicated for all patients.

In detail, 2 patients, respectively, aging 16 and 34 years experienced a left emimandibular ameloblastoma. A 71-year-old patient experienced right emimandibular ameloblastoma and a 68-year-old patient required a right mandibular resection for bisphosphonate-related osteonecrosis of the jaw.

Preoperative Preparations

In addition to routine head and neck staging procedures, which included a high-resolution computed tomography (CT) scan of the craniofacial skeleton, high-resolution CT angiography of the lower extremities was made according to a standard protocol to confirm a regular 3-vessel supply of the lower limb. DICOM files with an axial slice thickness of 0.6 mm were forwarded to the medical engineering partners (Materialise, Leuven, Belgium). The datasets were converted into 3-dimensional virtual bone models of the upper and lower jaws and the left fibula using Synthes ProPlan CMF software 3.0 (De Puy Synthes Maxillofacial, Paoli, CA/Materialise). The neomandibular segments of the fibula were then aligned within the defect to replace the crustal border of the mandible. Once the bony framework consisting of the native jaw and the fibular segments was prepared, the blueprint of a reconstruction plate was molded to the geometry of the lateral surface of the hybrid mandible. In 1 patient, 2 fibular segments were harvested; in other 2 cases, 3 fibula pieces to restore mandibular continuity were set up and in the remaining case, it was necessary the preparation of 4 segments double barrel linked (Fig. 1A-D).

In the software program, the dummy reconstruction plate behaves like a rod, having viscoelastic flow characteristics that allow for a seamless fit without any recesses. The profile (thickness 2.4 mm), anatomic position, and span length of the plate were defined and the plate screw holes (number, location and angulation) were customized, resulting in a draft version of a patient-specific reconstruction plate (Synthes patient specific mandibular plate, Synthes Maxillofacial, Paoli, CA) with optimal stability. To bring the actual patient specific mandible plate (PSMP) into precise alignment with the native mandible and the neomandibular segments, the resection guides and the cutting guides for the fibula have hollow drilling cylinders to target the plate screw holes accurately onto the lateral surfaces of the native bony remnants and the fibular segments. The defined screw hole position must make allowance for potential interferences with osteotomy interfaces, tooth roots, nerves. Subsequent to the computer-assisted design, a set of personalized templates (jigs, guides) and physical models were fabricated with selective laser sintering (SLS) from polyamide (biocompatible photopolymer) and with stereo lithography (STL) technique respectively: 2 SLS mandibular resection/ plate screw hole positioning guides, an SLS fibula cutting guide, an STL-model of the mandible mapping the resectional defect, and a separate STL model of the assembled neomandibular segments. The 3D CAD data records were imported to the machining program for the numerically controlled 3D PSMP milling and drilling system.

Proplan project was entirely exported in a STL format, which was subsequently matched with the preoperative CT, thanks to VECTOR VISION navigation software (BrainLab curve Brain-Lab). Eight points on inferior tooths dental cusps were chosen to calibrate this navigation system (Fig. 2A-C).

Surgical Procedure

A cold-knife incision in a neck fold approximately 2 cm below the inferior mandibular border was performed. Preparation and elevation of the skin-muscle flap were subsequently carried out. After the exposure of the hemimandible and symphyseal region, the SLS resection guides were mounted on the ramus and to the symphisis, temporarily secured with 2.0 mm screws through the fixation holes. The resection borderline was marked out by the angled slot/flange block combination in the posterior guide and the vertical flange in the anterior guide.

A skull reference frame with 3 light-reflecting spheres DRF linked to a connector was fixed on the mandibular branch with 3 transcortical screws contralateral to the lesion to achieve the navigation of the whole mandibular arch, thanks to a greater mobility (Fig. 3A). Registration was completed through facial-surface imaging with the infrared ray emitter and receiver, as per Vector Vision protocol. The registration error threshold was fixed <0.7 mm and in all cases software verified registration accuracy of the surgical area automatically. Also, surgeons could verify the actual surgical process on the virtual plan. The plate screw holes for the eventual seating of the PSMP to the residual mandibular sections were drilled via the targeting cylinders before

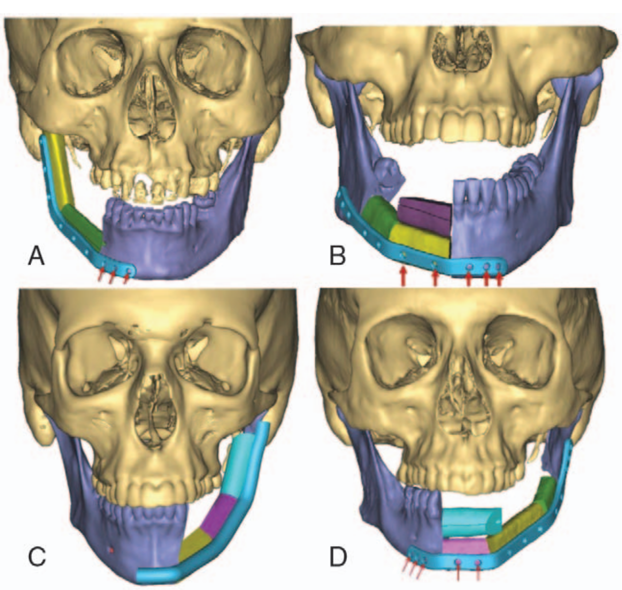

FIGURE 1. Our case series planned on Proplan CMF. (A) Two fibula segment for mandibular reconstruction; (B and C) two cases three fibula pieces to restore mandibular continuity; (D) 4 segments double barrel linked reconstruction.

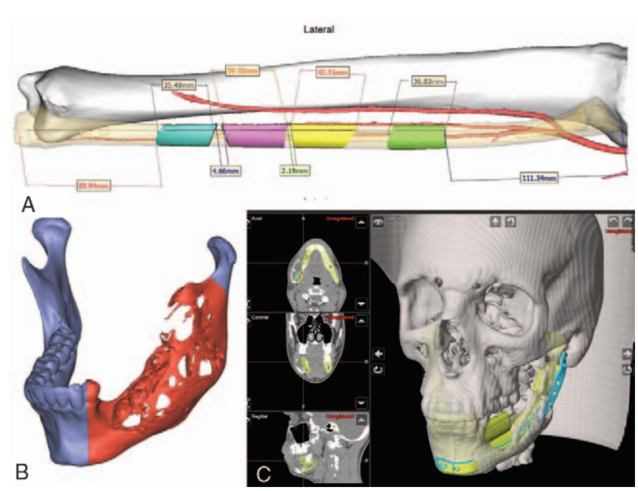

FIGURE 2. (A) Proplan CMF fibula model with surgical osteotomies segment defined according to the mandibula profile. (B) Three-dimensional model of mandible with segment to be resected in red. (C). Ct overlapping at Brain vector vision software showing the superimposition of the reconstructed segment inside the preoperative computed tomography scan.

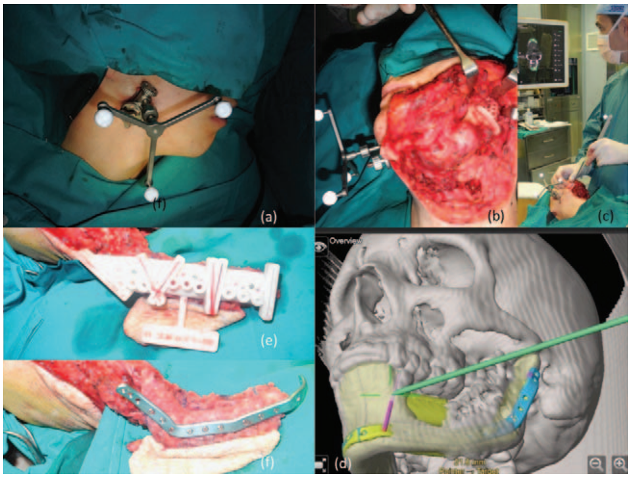

FIGURE 3. (A) Intraoperative picture showing the DRF, secured directly on the mandibular branch controlateral to the surgery. (B and C) Intraoperative image showing the surgeon checking the correct positioning of the osteotomic guides on the mandible as shown on the (D) image-guidance system. (E and F) CAD templates on the harvested fibula, which later on has been modeled and stabilized by the Synthes patient-specific mandibular plate (F).

the resection. The line of the mandibulectomy was guided by the navigation system (Fig. 3B-D).

Simultaneously, the osteoseptomyocutaneous fibular flap including a spindle-shaped skin island with 2 perforators was dissected from the left lower leg under tourniquet via a standardized lateral access. The SLS fibula cutting guide was placed in a reproducible position on the lateral surface of the fibula measured from the tip of the lateral malleolus and fastened with a pair of 2.0-mm screws (monocortical fixation) through the designated fixation holes in each devised segment. After completion of the harvest and sideward mobilization of the composite flap still on its vascular pedicle, the seating holes to interconnect the PSMP and the bone segments were targeted through the hollow cylinders of the cutting guide and drilled (Fig. 3E). Only then were the angled shortening cuts and the wedge osteotomy along the flanges of the guide accomplished. To ensure a proper fit at the recipient site, the fibular segments were placed within the defect of the STL mandible model. Thereafter, the PSMP was applied and fixed with 2.4-mm locking screws and the tourniquet released to start the reperfusion. (Fig. 3F) Wound closure of the leg was begun caudally and the peroneal vessels were ligated and cut after a short interval. The free fibula flap/PSMP construct was then moved to the mandible/neck area to be incorporated into the defect. (Fig. 4A and B) The bone segments and plate arms had a perfect fit and rigid fixation with 2.4-mm bicortical locking screws was accomplished via the predrilled (targeted) boreholes within a few minutes. Thereafter, the microvascular reanastomoses were established with the superior thyroid artery, the external jugular vein, and the facial vein as recipient vessels, the skin paddle was sutured into the oral mucosa defect, and the neck wounds closed.

Postoperative Findings

CT imaging done 3 weeks postoperatively demonstrated the accuracy of the reconstruction. 3D rendering of bone contours was reconstructed from the postoperative CT and exported into STL files. Preoperative and postoperative data of each patient were imported into Cloud Compare Open source software Version: 2.7.0. Manual and global registration functions were used to match the nonsurgical parts of the 2 models. Through the "mash compare"

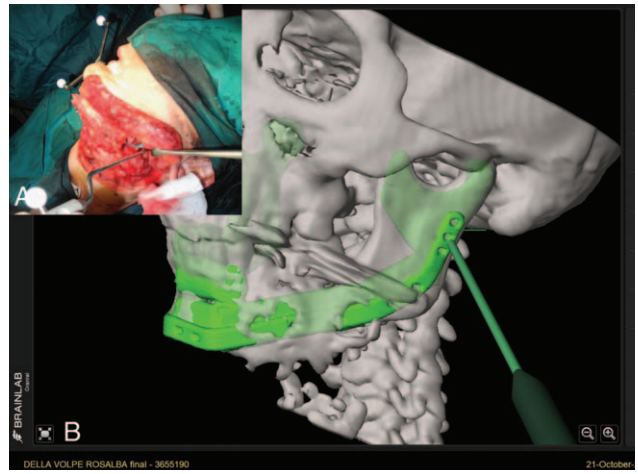

FIGURE 4. (A) Intraoperative images showing the probe checking the correct position as shown on the vector vision monitor (B) of the distal screw inside the fixation plate.

function the software has measured in each case, the distance between the mash points in the pre and post imported STL models, calculated the standard deviation, and generated a color map to highlight the overlapping areas (Fig. 5A-D). The results were: close approximation between the patient-specific mandibular plate and fibular segments, congruence at the bony interfaces between native mandible and fibular segments and intersegmentally. The matching standard deviation (SD) ranges from 0.33 to 8.9 (mean SD 4.67).

DISCUSSION

During the past 30 years, the spread of the CAS techniques, which mainly consist of CAD, CAM, RP, and surgical navigation technique, has been used in a lot of surgical procedures worldwide, such as in oral and maxillofacial surgery. First of all, computerized navigation has improved the reliability and the outcomes of mandibular resections and reconstructions, by providing realtime feedback to surgeon.[7,14–16] Before the spread of this innovative tool, osteotomies were surgeon-depending mode performed. Osteotomic lines were carried out basing on tumor visualization keeping away

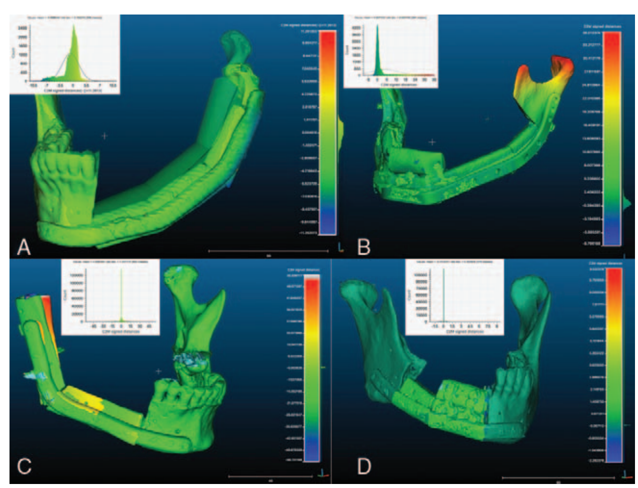

FIGURE 5. (A-D) Colored maps and overlapping diagrams, edited with Cloud Compare software, demonstrating the superimposition between the preoperative and postoperative STL model in each cases reported in our series.

from the lesion. The same occurred for mandibular reconstructions. One of the greatest challenges in mandibular reconstruction is how to most accurately shape and fix vascularized bone flaps so that the symmetry and function of the face are restored optimally. As well as reestablishing mandibular continuity, the goal of reconstruction surgery is to restore facial contours and dental occlusion.[1] Computer-aided navigation is based on synchronization of the intraoperative position of the patient with the image of the patient's anatomy obtained previously by CT or magnetic resonance imaging. Synchronization is realized through image registration and motion tracking. This technique allows the surgeons to determine the location of any bony anatomic landmark to within approximately 1 to 2 mm.

To enable navigation in relation to the lower jaw, 3 methods have been used, according to literature. The first approach relies on maxillomandibular fixation, which is used to immobilize the mandible.[10] The second and more commonly used approach is based on positioning of the mandible in a reproducible position that allows its synchronization, and is based on centric occlusion of the teeth or the use of special templates.[13,17] Many authors, believing that the navigation system is not suitable for mandible surgery because of jaw's movement, use dental splints to fix the mandible to the skull to control the mobility. In this way, the light-reflecting spheres of the DRF were rigidly fixed to the skull and the mandible could be navigated. A third approach is to mount a special sensor frame onto the mandible, thereby allowing surgeons to track the position of the mandible optically and to compensate for its continuous movement during surgery. In this technical report, we want to evaluate the feasibility of mandibular surgical navigation by positioning the DRF directly on the mandibular branch, thus allowing mandible motility during the intervention.

We involved in our study 4 patients who underwent mandible resection with primary free fibula flap reconstruction of the segment.

Proplan project was entirely exported in a STL format, which was subsequently matched with the preoperative CT, thanks to VECTOR VISION navigation software (BrainLab curve BrainLab). Eight points on inferior tooths dental cusps were chosen to calibrate this navigation system. A skull reference frame with 3 light-reflecting spheres DRF linked to a connector was fixed on the mandibular branch with 3 transcortical screws contralateral to the lesion to achieve the navigation of the whole mandibular arch, thanks to a greater mobility. Registration accuracy of the surgical area was verified automatically by the software, and registration errors were <0.7 mm in all cases. Also, surgeons could verify the actual surgical process on the virtual plan. The plate screw holes for the eventual seating of the PSMP to the residual mandibular sections were drilled via the targeting cylinders before the resection. The line of the mandibulectomy was guided by personalized jigs and checked by the navigation system (Fig. 3B-D).

CT imaging done 3 weeks postoperatively demonstrated the accuracy of the osteotomies. 3D rendering of bone contours was reconstructed from the postoperative CT and exported into STL files. Preoperative and postoperative data of each patient were imported into Cloud Compare Open source software Version: 2.7.0. Manual and global registration functions were used to match the nonsurgical parts of the 2 models. Through the "mash compare" function, the software has measured in each case the distance between the points in the pre and post imported STL models, calculated the standard deviation, and generated a color map to highlight the overlapping areas (Fig. 5A-D). The close overlap between the pre and post models with an average SD of 4.7 mm shows how the surgical navigation of the jaw with the technique shown may be a valid method to apply for jaw surgeries. However, the little discrepancy between the navigation intraoperative indications and the actual surgical result tested by postoperative CT imaging could occur and could depend on technical, imaging, registration, application, and surgeon-made errors. Doubtless registration, responsible for linking the virtual planning with the surgical site, is the key element.

CONCLUSIONS

The method described in our series has allowed an accurate surgical navigation of the jaw without the need of intermaxillary fixation. To our knowledge, this is the first-time description of such a kind of method to navigate the jaw positioning the DRF directly on the mandibular branch to maintain the full mobility of the mandible. This technique could greatly facilitate resection and reconstructive surgical procedures of the jaw while ensuring precision and accuracy. The encouraging results obtained in the present report suggest to further investigate the possibilities of this technique to better define the method and its indications.

REFERENCES

1. Girish Rao S, Aditya TN, Gopinath KS, et al. Free fibula flap in the reconstruction of mandible: a report of six cases. *J Maxillofac Oral Surg* 2009;8:275–278
2. Zheng GS, Su YX, Liao GQ, et al. Mandible reconstruction assisted by preoperative simulation and transferring templates: cadaveric study of accuracy. *J Oral Maxillofac Surg* 2012;70:1480–1485
3. Shan XF, Li RH, Lu XG, et al. Fibular free flap reconstruction for the management of advanced bilateral mandibular osteoradionecrosis. *J Craniofac Surg* 2015;26:e172–e175
4. Succo G, Berrone M, Battiston B, et al. Step-by-step surgical technique for mandibular reconstruction with fibular free flap: application of digital technology in virtual surgical planning. *Eur Arch Otorhinolaryngol* 2015;272:1491–1501
5. Yadav PS, Gazwan QA, Shankhdhar VK, et al. A simple and cost effective template for central segment reconstruction of mandible with free fibula flap. *J Maxillofac Oral Surg* 2010;9:256–260
6. Colletti G, Autelitano L, Rabbiosi D, et al. Technical refinements in mandibular reconstruction with free fibula flaps: outcome-oriented retrospective review of 99 cases. *Acta Otorhinolaryngol Ital* 2014;34:342–348
7. Hanasono MM, Skoracki RJ. Computer-assisted design and rapid prototype modeling in microvascular mandible reconstruction. *Laryngoscope* 2013;123:597–604
8. Saad A, Winters R, Wise MW, et al. Virtual surgical planning in complex composite maxillofacial reconstruction. *Plast Reconstr Surg* 2013;132:626–633
9. Yu H, Shen SG, Wang X, et al. The indication and application of computer-assisted navigation in oral and maxillofacial surgery-Shanghai's experience based on 104 cases. *J Craniomaxillofac Surg* 2013;41:770–774
10. Bettschart C, Kruse A, Matthews F, et al. Point-to-point registration with mandibulo-maxillary splint in open and closed jaw position. Evaluation of registration accuracy for computer-aided surgery of the mandible. *J Craniomaxillofac Surg* 2012;40:592–598
11. Wilde F, Cornelius CP, Schramm A. Computer-assisted mandibular reconstruction using a patient-specific reconstruction plate fabricated with computer-aided design and manufacturing techniques. *Craniomaxillofac Trauma Reconstr* 2014;7:158–166
12. Huang JW, Shan XF, Lu XG, et al. Preliminary clinic study on computer assisted mandibular reconstruction: the positive role of surgical navigation technique. *Maxillofac Plast Reconstr Surg* 2015;37:20
13. Shan XF, Chen HM, Liang J, et al. Surgical navigation-assisted mandibular reconstruction with fibula flaps. *Int J Oral Maxillofac Surg* 2016;45:448–453

14. Schramm A, Gellrich NC, Gutwald R, et al. Indications for computer-assisted treatment of cranio-maxillofacial tumors. *Comput Aided Surg* 2000;5:343–352
15. Schultes G, Karcher H, Gaggl A, et al. Computer assisted tumour resection of the skull base: case report. *J Craniomaxillofac Surg* 2001;29:326–331
16. Ciocca L, Mazzoni S, Fantini M, et al. CAD/CAM guided secondary mandibular reconstruction of a discontinuity defect after ablative cancer surgery. *J Craniomaxillofac Surg* 2012;40:e511–e515
17. Wu J, Sun J, Shen SG, et al. Computer-assisted navigation: its role in intraoperatively accurate mandibular reconstruction. *Oral Surg Oral Med Oral Pathol Oral Radiol* 2016;122:134–142