Navigation-Assisted Mandibular Body Distraction Osteogenesis: A Preliminary Study in Goats

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Purpose: The purpose of the present study was to evaluate the accuracy of navigation-assisted distraction osteogenesis of the mandible in a goat model.

Materials and Methods: Six adult goats were included in the present study. A 3-dimensional (3D) image was reconstructed by performing computed tomography (CT) scans in 0.625-mm slices after placement of 5 maxillary marking screws and intermaxillary fixation with a prefabricated occlusal splint using the TBNavis-CMFS navigation system (Multifunctional Surgical Navigation System, Shanghai, China). Simulation distraction was performed to lengthen a unilateral mandibular body by 10 mm. Image-guided distraction osteogenesis was performed on the goat hemimandibles according to the preoperative planning. 3D skeletal measurements from the simulation were compared with those taken from the CT scans at 3 months postoperatively.

Results: Navigation-assisted distraction osteogenesis was successfully performed in all 6 goat hemimandibles. The accuracy of the intraoperative registration was within 1 mm. The hemimandible was lengthened a mean of 10.02 mm (range 9.89 to 10.12). No significant differences were found between the simulation distraction and postoperative 3D measurements (P > .05).

Conclusions: Navigation-assisted distraction osteogenesis of the mandible in the goat model can be performed with high accuracy using the TBNavis-CMFS navigation system.

Distraction osteogenesis has become an accepted treatment option in the treatment of patients with complex craniofacial deformities. Syndromic patients often present with complex 3-dimensional (3D) soft and hard tissue deformities that require simultaneous surgical intervention. The current advances in helical computed tomography (CT) have enabled surgical teams to visualize the vital anatomic structures such as the optic nerve, inferior alveolar nerve, and developing tooth buds with high accuracy. The imaging technology has also allowed accurate assessment and measurement of bony deformities. The images can be

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reconstructed and manipulated in a 3D platform to facilitate appropriate treatment planning. The 3D simulation software enables surgeons to determine the most favorable osteotomy to improve the outcomes and avoid complications. Thus, conventional 2-dimensional methods of assessing facial skeleton will be of limited value in managing cases of complex facial skeleton deformity.

With the recent development of 3D preoperative planning for craniomaxillofacial distraction osteogenesis, the surgical outcomes have become more predictable. Varol and Basa\(^1\) reported that 3D computer-aided surgical simulation and model surgery can provide accurate orientation of the distraction vectors for pre-maxillary and internal trans-sinusoidal maxillary distraction. Robiony et al\(^2\) concluded that virtual planning and rapid prototype techniques were effective in correcting complex maxillofacial skeletal deformities.

Despite the current advances in computer-assisted planning, transferring the preoperative planning to the actual surgery has remained problematic. The process often involves stereolithographic model construction, surgical guide construction, and prebending of fixation devices. The multiple stages required to transfer the preoperative plan are potential sources of error and add complexity to the procedure. Navigation-guided surgery has been used in dental implants, foreign body removal, deformity correction, and craniomaxillofacial reconstruction\(^3,6\). The application of navigation technology in the area of craniofacial distraction osteogenesis has not yet been reported.

The purpose of the present study was to establish an animal experimental protocol for navigation-guided mandibular distraction osteogenesis.

**Materials and Methods**

**PREOPERATIVE PREPARATION AND SIMULATION**

The laboratory of animal study, local institutional review board, and ethics committee of Shanghai Ninth People’s Hospital, Shanghai Jiaotong University, approved the present study.

Six adult goats were included in the present study. Five titanium screws were placed in the maxillary alveolus as navigation markers, and 4 intermaxillary screws were placed for intraoperative intermaxillary fixation (IMF). Using a prefabricated occlusal splint and IMF, preoperative CT scans were obtained for each goat to ensure predictable and reproducible condylar positioning (0.625 mm thickness, light speed 16; GE, Gloucestershire, UK). The Digital Imaging and Communications in Medicine data from the CT scans were converted into stereolithography format using MIMICS software, version 8.11 (Materialise, Leuven, Belgium), compiled into 2-dimensional axial images, and the data were presented in axial, coronal, sagittal, and 3D reconstructions. A unilateral mandibular body distraction osteogenesis was designed, and 2.5-cm mandibular distractor was mapped into the TBNAVIS-CMFS Navigation System (Multifunctional Surgical Navigation System, Shanghai, China). The osteotomy line was located distal to the second molar and perpendicular to the mandibular lower border. The simulation distraction osteogenesis was performed, and 3D measurement of the jaw structures was performed 3 times for each goat by a senior clinician after the mandible had been lengthened 10 mm (Table 1). At the end of planning, the positioned distraction device and osteotomy line were shown on the screen, ready for surgery.

**NAVIGATION SURGERY**

The procedure was performed with the goats under general anesthesia. Intraoperative IMF with a prefabricated occlusal splint was applied to the upper and lower jaw to ensure the condylar position. The digital reference frame (DRF) was fixed rigidly to the subject’s frontal bone. The navigation system was activated and calibrated with help of the computer engineer. The infrared camera emitted infrared light, which was reflected by the DRF and detected by the receiving device. It enabled real-time calibration between the actual skeleton and the virtual skeleton within the work station. The individual registration process was completed using the navigation probe and the maxillary positioning screws.

The accuracy of registration was calculated and checked using anatomic landmarks (eg, tooth cusp). The registration procedure should be repeated if the discrepancy between the actual and virtual image is greater than 1 mm. The 3D location of the surgical instruments and the surrounding anatomic structures was precisely displayed on the interactive navigation system (Fig 1).

After exposure of the mandibular body using an extroral approach, the navigation probe was used to detect the position of the preplanned osteotomy site. A navigated drill was used to complete all distractor screw hole drilling according to the simulated skeleton on the computer screen. The distractor was applied to the mandible, and the navigation probe was used to confirm distractor positioning. The distractor was removed, and mandibular osteotomy was completed using the navigated drill and osteotome. The distractor was reapplied and tested after IMF release. The final position of the distracted mandible was checked using the navigation probe (Figs 2,3).

**POSTOPERATIVE MANAGEMENT**

After a 3-day latency period, the distractor was activated twice daily (1 mm/day of lengthening), and the mandible was distracted 10 mm forward, in accordance
with the preoperative planning. A postoperative CT examination was performed after 3 months. 3D measurements were performed 3 times for each skeleton using the same navigation software, and all the measurements were completed and recorded by the same examiner.

The acquired data were analyzed using parametric Student’s $t$ tests. The tests were performed using the Statistical Package for Social Sciences, version 13.0 (SPSS, Chicago, IL), and the results were considered significant if $P < .05$.

### Table 1. MEASUREMENTS OF GOAT MANDIBLE

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CoL-GoL</td>
<td>Distance between top of condyle and mandibular angle point on left side</td>
</tr>
<tr>
<td>CoR-GoR</td>
<td>Distance between top of condyle and mandibular angle point on right side</td>
</tr>
<tr>
<td>GoL-Me</td>
<td>Distance between mandibular angle point and chin point on left side</td>
</tr>
<tr>
<td>GoR-Me</td>
<td>Distance between mandibular angle point and chin point on right side</td>
</tr>
<tr>
<td>CoL-CoR</td>
<td>Distance between bilateral condyle points</td>
</tr>
<tr>
<td>GoL-GoR</td>
<td>Distance between bilateral mandibular angle points</td>
</tr>
<tr>
<td>$\angle$ GoL-Me-GoR</td>
<td>Angle of left mandibular angle point to chin point and right mandibular angle point to chin point</td>
</tr>
<tr>
<td>$\angle$ Co-Go-MeL</td>
<td>Angle of condyle point to mandibular angle point and mandibular angle point to chin point on left side</td>
</tr>
<tr>
<td>$\angle$ Co-Go-MeR</td>
<td>Angle of condyle point to mandibular angle point and mandibular angle point to chin point on right side</td>
</tr>
</tbody>
</table>

Results

The accuracy of each registration measured using TBNavis-CMFS system was within 1 mm. All navigation-guided operations and postoperative distraction procedures were uneventful. No complications were observed, and the mandible was lengthened from 9.89 to 10.12 mm (mean 10.02). A comparison of the simulated and postoperative 3D measurements of the mandible showed no significant differences ($P > .05$; Table 2, Fig 4).

Discussion

Intraoperative navigation technology, originally developed for neurosurgical applications, has gained increasing acceptance in oral and craniomaxillofacial surgery in recent years. The major advantages of this technique include confirmation of invisible anatomic structures and improvements in operative accuracy. Schmelzeisen et al. reported on navigation-guided skull base surgery and surgical reduction of orbital fractures and considered that navigation procedures could achieve precise and predictable results. Bell and Markiewicz concluded that preoperative computer modeling and intraoperative navigation provide useful guides for, and presumably more accurate reconstruction of, complex orbital injuries and postablative orbital defects.

The direction of distraction device placement determines the vector of mandibular distraction. The accuracy of transferring the ideal preoperative plan into the actual surgical procedure is of paramount importance in obtaining an optimal clinical outcome. Using the navigation technique, a specific navigation probe and navigated drill can be permanently tracked on the screen during the procedure. The location of the simulated distractor could be detected intraoperatively, and the fixation holes were drilled once the planned vector axis had been confirmed. The results indicated that positioning of the vector could be easily evaluated and controlled with high accuracy.

The limitations of common rapid prototyping technique for surgical planning have been the unrepeatability and the low cost-effectiveness. The precision might be unreliable because of the potential distortion or damage of the prebent device prepared for the surgical operation using the preoperative planning model.
Navigation-guided surgery can avoid these problems. It provides unlimited numbers of preoperative simulations in a 3D platform. It allows accurate intraoperative instrument positioning and continuous tracking of the navigated instruments. It also improves the intraoperative safety, because vital structures, such as the inferior alveolar nerve and tooth germ, can be visualized on the computer screen and avoided if necessary.

Although the advantages of navigation technology have been well acknowledged by maxillofacial surgeons, few references on craniofacial distraction osteogenesis have been documented. In 2005, d’Hauthuille et al. compared the feasibility and reliability of a customized stereolithographic template technique and a computer-assisted surgery method that guided the osteotomy and positioning and screwing of the distractor device in a fresh cadaver study. The results showed that the accuracy of the 2 techniques appeared comparable. Another single case study indicated that the intraoperative navigation system provides an added tool during frontofacial surgery that enables the surgeon to visualize the complex anatomy and improve the accuracy of distraction device placement. Man-
Occlusal splint should be constructed before preoperative CT acquisition and used to guide mandibular positioning during the navigation-guided surgery. Occlusal splint-guided IMF can avoid unwanted mandibular movement. The DRF can be used to locate the frontal bone and intraoperative IMF maintains a stable maxillomandibular relationship. Another method has been to mount a reference frame onto the mandible to compensate its movement during surgery. Casap et al concluded that direct tracking of the lower jaw using a teeth-mounted sensor frame and teeth-supported fiducial markers were superior to indirect tracking in lower jaw surgery. However, mounting a reference frame with a bulky navigation sensor onto the mandible can limit the surgical access for intraoral procedures. Electromagnetic technology is an alternative that does not require the user to maintain a line of sight between the instrument and a camera. An electromagnetically tracked pencil can be used for mandibular marking intraoperatively; however, the device and algorithms require revision to decrease error. The currently available major commercial craniofacial navigation products do not have public access for editing and/or modification of mandibular distraction osteogenesis. The new apparatus designed for mandible-based navigation procedures has been tested in our system and will be used in future studies.

The main disadvantages of our protocol include the morbidity of maxillary fiducial marker placement and DRF implantation. This problem could be solved by developing a mandibular-based approach, as mentioned. Also, an experienced staff member is required to manipulate the navigation system during the entire surgical procedure. Another disadvantage is that the operation time could be prolonged because of regulation of the head frame position, landmark checking,
instrument calibration, and the necessity for restarting the registration process.

The present study could have been improved by including a control group, such as a traditional distraction procedure or rapid prototype modeling planning. Continued integration of different types of distractors and surgical instruments into the system will facilitate applying this technique to different maxillofacial surgical procedures.

In conclusion, the feasibility of unilateral mandibular distraction osteogenesis was tested using the image-guided navigation system TBNavis-CMFS. It enabled the surgeon to transfer the preoperative plan directly to the actual operation with high accuracy. This preliminary study has provided a protocol for navigation-guided mandibular distraction osteogenesis.

References