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# Computer assisted positioning of the proximal segment after sagittal split osteotomy of the mandible: Preclinical investigation of a novel electromagnetic navigation system

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A B S T R A C T

*Introduction:* Modifications of the temporomandibular joint position after mandible osteotomy are reluctantly accepted in orthognathic surgery. To tackle this problem, we developed a new navigation system using miniaturized electromagnetic sensors. Our imageless navigation approach is therefore optimized to avoid complications of previously proposed optical approaches such as the interference with established surgical procedures and the line of sight problem.
*Material and methods:* High oblique sagittal split osteotomies were performed on 6 plastic skull mandibles in a laboratory under conditions comparable to the operating theatre. The subsequent condyle reposition was guided by an intuitive user interface and performed by electromagnetic navigation. To prove the suitability and accuracy of this novel approach for condyle navigation, the positions of 3 titanium marker screws placed on each of the proximal segments were compared using pre- and postoperative Cone Beam Computed Tomography (CBCT) imaging.
*Results:* Guided by the electromagnetic navigation system, positioning of the condyles was highly accurate in all dimensions. Translational discrepancies up to 0,65 mm and rotations up to 0,38° in mean could be measured postoperatively. There were no statistically significant differences between navigation results and CBCT measurements.
*Conclusion:* The intuitive user interface provides a simple way to precisely restore the initial position and orientation of the proximal mandibular segments. Our electromagnetic navigation system therefore yields a promising approach for orthognathic surgery applications.


## 1. Introduction

Malocclusions are among the most common oral pathologies world-wide (Tausche, 2004; Gábris et al., 2006; Nobile et al., 2007; Grando et al., 2008; Arora and Bhateja, 2015; Dimberg et al., 2015). Surgical techniques such as the Le Fort I Osteotomy of the maxilla, the Bilateral Sagittal Split Osteotomy (BSSO) of the mandibular ramus and the High Oblique Split Osteotomy (HSSO) are well described (Scheuer and Höltje, 2001; Obwegeser, 2007; Patel and Novia, 2007). In addition to clinical assessment, cephalometric analysis and treatment planning, model surgery on dental casts and fabrication of patient specific intermaxillary splints for surgical planning transfer are commonly required.

The role of unaffected condyle positioning after osteotomy of the mandible is discussed controversially (Ellis, 1994). Indeed, postoperative orthognathic results of the correct condyle positions provide long-term occlusal stability and reduce the number of early relapses (Will et al., 1984). Thus, a displacement of the condyles may provoke morphologic changes of the capitulum, subsequently leading to dysfunction of the temporomandibular joint complex (Arnett, 1993; Wolford et al., 2003). Different techniques such as intraoperative condylar repositioning devices (Lee et al., 2013) as well as computer-assisted condyle positioning (Marmulla and Mühling, 2007) have been applied to cope with this problem.

Aside from the desire to keep the condyles in the preoperative position during orthognathic surgery, there are cases that require a

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different position of the condyle within the temporomandibular joint, which necessarily requires the integration of imaging. The use of electromagnetic (EM) tracking systems has been introduced successfully in maxillofacial surgery with a high accuracy for passive position tracking of the upper jaw after Le Fort I osteotomy (Berger et al., 2015). Employing an EM field generator which provides a cubic working volume with an edge length of 0.5 m and multiple sensing coils, our navigation system helps to improve the surgical outcome with a minimally invasive approach, and consequently, to overcome limitations and systematic errors caused by splints and face bow recordings (Chow et al., 1985; Barbenel et al., 2010; Agbaje et al., 2013).

Therefore, the aim of this preliminary study was to evaluate the accuracy of condyle repositioning after HSSO in orthognathic surgery on phantom skulls using our EM navigation system to avoid condyle dislocations of the temporomandibular joint complex.

## 2. Material and methods

Our analyses were performed on 6 plastic skull phantoms of natural size (HeineScientific, Wasserbillig, Luxembourg). For imageless navigation, the initial position of the condyles and five skull landmarks were recorded prior to osteotomy. All phantoms underwent bilateral HSSO of the mandibular ramus with different target positions using standard wax splints. Then, proximal mandible segments were navigated with our EM system to restore the initial position of the condyle. Preoperative and postoperative computed tomography (CT) was employed to evaluate the accuracy of our system.

### 2.1. Surgical approach

The treatment was done under a reproducible laboratory operating room (OR) setting. The environment was comparable to that of a real OR with an operating table. Prior to osteotomy, a preoperative CT scan of every phantom skull was acquired. The registration of the coordinate system and initial sensor positions were carried out with the EM navigation system. Subsequently, each phantom skull underwent HSSO of the mandible, fixating the new occlusal position of the lower jaw with a wax splint.

Splints were fabricated with auto polymerizing resin and used to relocate the mandible at 6 different positions: 3, 5 and 8 mm forward and backwards, respectively. Thereafter, the left and right condyle were navigated to the initial position recorded preoperatively. Condyles were fixated with 10-hole titanium plates, and postoperative cone beam CT scans were acquired.

### 2.2. Recording of sensor positions and landmarks

Unlike most of the optical navigation systems, our imageless approach does not require a patient-to-image registration. Navigation of bone segments is carried out with respect to the relative position of EM sensors (attached to the bones) inside the electromagnetic field, based upon their mutual coordinate system.

Although this work only evaluates the condyle reposition, the whole navigation system is intended to assist mandibular and maxillary osteotomies. A virtual coordinate system is therefore required to properly interpret the amount and direction of planned surgical corrections and to display useful navigation instructions. Thus, the same coordinate system used preoperatively for clinical assessment purposes is virtually reproduced. The navigation system uses the Frankfort Horizontal (FH), midsagittal and coronal planes to build a virtual cephalometric coordinate system. FH is estimated using a principal component analysis (PCA) (Jolliffe, 2002) of four hard tissue landmarks: left & right porion (upper margin of the porus acusticus externus) and left & right orbitale (inferior margin of the orbit). The midsagittal plane is considered to be perpendicular to FH and passes through the midpoint of the frontonasal suture (Nasion) and FH centre point. The coronal plane is computed perpendicular to both the FH and midsagittal planes. A similar approach is described by Swennen et al. to orientate CT data sets in a standardized manner (Swennen et al., 2005). All required anatomical landmarks are captured using an electromagnetic pointer and the computed virtual coordinate system is transformed to match the orientation of the patient's head. An electromagnetic sensor is attached to each mandibular ramus, and the initial position of both sensors is registered preoperatively in best occlusion with the upper jaw, registering indirectly the initial position of the corresponding condyle. In our setting, the initial position of each sensor represents the expected position after osteotomy of each mandibular ramus. Thus, navigating the attached sensor to the initial position will bring back the condyle to the initial position before osteotomy. Since the real position of each condyle is indirectly registered and restored, there is no need to record any landmark on the ascending ramus.

### 2.3. System implementation

EM measurements are performed with the tracking system Aurora V2 (NDI – Northern Digital Inc., Waterloo, Canada) at a maximum rate of 40 Hz and processed simultaneously by the navigation software, updating the visualization of both the position and orientation of bone models in real time. The navigation software was programmed in C++ using Microsoft Visual Studio 2012 (Microsoft Corporation, Redmond, WA, USA) with a Qt Add-In. A self-implemented library was used for the communication of the EM tracking system and the navigation software. Since no real imaging was employed, generic bone segment models were used for intuitive visualization of target and real condyle positions. Navigation views are fully customizable preoperatively by the user (bone representations, colours, axes, bounding boxes) and may be adjusted intraoperatively. Sensor data and data structures are continuously stored in order to reproduce the surgery for subsequent analysis. Moreover, this feature allows one to suspend and resume the navigation procedure at any arbitrary time-point.

#### 2.3.1. EM sensors

To provide high precision navigation results, specific bone-attachable six degrees of freedom (6-DoF) sensors were manufactured using a non-ferromagnetic and biocompatible titanium-aluminium-vanadium alloy (fiagon GmbH, Berlin, Germany) to avoid possible field distortions and ensure sterilization resistance. To constantly track the patient's head position a reference sensor is attached to the zygomatic bone. Additionally, each condyle is tracked with an individual sensor which does not hinder the surgeon in his movements or dental occlusion (Fig. 1).

### 2.4. Navigation of bone segments

EM navigation is visualized in real time and surgical movements are guided by four views of the navigation system interface. Figs. 2–4 illustrate the perspective (3D), coronal, sagittal and transversal views while the proximal mandibular-segment is approaching the target position guided by the navigation system. Translation and rotation of the proximal mandibular segment are calculated for each orthogonal projection along FH, midsagittal and coronal plane simultaneously. This representation of bone segments supports an efficient navigation toward that target position. Required movements (direction and amount) are also indicated at the top of each 2D-view while the 3D-view summarizes the