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# Validation of anatomical landmarks-based registration for image-guided surgery: An in-vitro study

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ABSTRACT

*Introduction:* Perioperative navigation is a recent addition to orthognathic surgery. This study aimed to evaluate the accuracy of anatomical landmarks-based registration.
*Materials and methods:* Eighty-five holes (1.2 mm diameter) were drilled in the surface of a plastic skull model, which was then scanned using a SkyView cone beam computed tomography scanner. DICOM files were imported into BrainLab ENT 3.0.0 to make a surgical plan. Six anatomical points were selected for registration: the infraorbital foramena, the anterior nasal spine, the crown tips of the upper canines, and the mesial contact point of the upper incisors. Each registration was performed five times by two separate observers (10 times total).
*Results:* The mean target registration error (TRE) in the anterior maxillary/zygomatic region was $0.93 \pm 0.31$ mm ($p < 0.001$ compared with other anatomical regions). The only statistically significant inter-observer difference of mean TRE was at the zygomatic arch, but was not clinically relevant.
*Conclusion:* With six anatomical landmarks used, the mean TRE was clinically acceptable in the maxillary/zygomatic region. This registration technique may be used to access occlusal changes during bimaxillary surgery, but should be used with caution in other anatomical regions of the skull because of the large TRE observed.


## 1. Introduction

Navigation systems are widely used in the operating room to improve surgical accuracy. In oral and maxillofacial surgery, there have been clinical reports detailing the successful implementation of navigation systems for various operations (Lubbers et al., 2011a), including implant placement (Widmann et al., 2007; Xiaojun et al., 2007), trauma (Yu et al., 2010; Markiewicz et al., 2012), foreign body removal (Eggers et al., 2009a; Verhaeghe et al., 2012), tumor resection (Lubbers et al., 2011c), and orthognathic surgery (Lo et al., 2010).

In bimaxillary orthognathic surgery, in which the maxilla is mobilized first, an intermediate splint is used to bring the maxilla to the planned position. However, by principle the splint only allows control of occlusion in the transverse and sagittal position, the vertical position is not controlled. A number of inaccuracies can occur in the axial, frontal, and sagittal planes due to the mobility of the lower jaw, potential inaccuracies in preoperative face-bow registration, cast surgery, differences in joint compressibility, uneven manual compression by the surgeon between left and right during LeFort I intrusion (especially when dealing with asymmetries), bony interferences at the pterygoids in posterior impactions, and difficulty in maintaining manual control of a (multi-) segmented maxilla in all dimensions. Although an external pin at the base of the nose is a reference point for the evaluation of vertical positioning of the upper incisor edge, this linear length also depends on the sagittal change of the repositioned maxilla.

Due to these potential errors introduced through mandibular positioning, even a good intermediate splint may result in inaccurate sagittal positioning, and vertical asymmetric canting of the occlusal plane. Currently available techniques to diminish these

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inaccuracies are non-navigational (Schwestka et al., 1990; Kretschmer et al., 2009; Fuglein and Riediger, 2011). Although navigation may be considered an additional tool to evaluate the accuracy of maxillary repositioning after LeFort I osteotomy, there have been few reports about this technique.

Hohlweg-Majert et al. (2005) state that precise registration of the system is the main precondition to attain acceptable accuracy. Different registration methods exist and can be categorized in two groups: marker-based registration and marker-free registration.

The use of a registration template is a well-known non-invasive method that has proven to be reliable and accurate regarding registration results (Luebbers et al., 2008; Eggers et al., 2009a,b; Widmann et al., 2010; Bettschart et al., 2011). The average accuracy of the template-based registration is between 1 and 2 mm. This device can be placed on the occlusal surface of patients, or be fixed to three intra-oral reference points (Widmann et al., 2010) in completely edentulous patients. However, this method has its disadvantages. To use a registration template, this device must be fabricated prior to the operation, which requires additional preparation work. In bimaxillary surgery, one potential source of error is poor stability of the registration template because of the interference of orthodontic hooks.

Self-drilling screws were inserted into the maxillary or mandibular region under local anesthesia to serve as registration points (Yu et al., 2010). This method provides even more accurate results (Luebbers et al., 2008). However, the technique is invasive and requires an additional surgical procedure to place the screws prior to the operation, and in our experience causes pain and discomfort to patients.

Laser surface scanning is a commonly applied marker-free method (Raabe et al., 2002; Schlaier et al., 2002; Marmulla et al., 2003, 2004; Hoffmann et al., 2005). The accuracy level of the laser surface scanning usually is around 2 mm (Raabe et al., 2002; Schlaier et al., 2002; Hoffmann et al., 2005; Lubbers et al., 2011b). During bimaxillary surgery, the clinical challenge is that nasal intubation is used. In this case, the patient's facial profile is modified between cone beam computed tomography (CBCT) acquisition and the surgical procedure. Marmulla et al. (2006) reported that a facial skin shift could reduce the mean target registration error (TRE) from 1.1 mm (laser scan while lying down) to 1.7 mm (laser scan while sitting up). According to these studies, surface registration accuracy is inadequate for bimaxillary surgery because of the huge mean TRE. In the previous investigations, a high-resolution laser scanner was utilized to perform surface registration in the clinical setting (Marmulla et al., 2003, 2004). A good registration result was achieved which was up to 1.1 $\pm$ 0.28 mm. In these studies, the system registered more than 100,000 cloud points of the patient's facial profile.

In contrast, in other studies (Raabe et al., 2002; Schlaier et al., 2002; Hoffmann et al., 2005; Luebbers et al., 2008) and normal clinical settings, the Z-touch® (BrainLab, Munich, Germany), which was a laser scanner for surface registration, acquired fewer than 1000 facial points for the registration. Although a high-resolution laser scanner is able to increase registration accuracy, this device brings additional high costs and is not universally available.

According to the published reports, there is no simple and accurate method, which is able to meet the clinical requirements of bimaxillary surgery. Anatomical landmarks are a natural feature, which could be utilized for registration. There are a few reports concerning the registration accuracy of anatomical landmarks. da Silva et al. (2010) reported that the use of anatomical landmark for registration was a reliable method with which to localize the junction of the transverse and sigmoid sinuses for retrosigmoid craniotomies. In his study, the registration accuracy is below 2 mm which does not satisfy the requirements of bimaxillary surgery. Other studies demonstrate that the accuracy of anatomical landmarks-based registration is even worse than 3 mm (Hardy et al., 2006; Metzger et al., 2007; Lubbers et al., 2011b). The main error source is that there are fewer definable bony landmarks on the cranium and lateral skull to be selected as registration point. Although the tips of the crowns are easier and clearly definable, in the previous investigations, there is no report concerning utilization of dentition structures as anatomical points for registration yet. Therefore, the aim of our study was to evaluate TRE in the context of anatomical landmarks-based registration. Anatomical points on the dental occlusal and cranium region were utilized.

## 2. Materials and methods

### 2.1. Data acquisition

A plastic skull model (type: A20. 3B Scientific GmbH, Germany) was prepared for use in this study (Fig. 1). Eighty-five target landmarks were created by drilling holes in the surface of the plastic skull model. The diameter of the drill bit was 1.2 mm to ensure that all of the target landmarks were clearly visible on the CBCT scan.

The skull model was then scanned using a SkyView CBCT scanner (Cefla dental, Italy). The scan parameters were 9 inch with dentition mode. Each slice was composed of 512 $\times$ 512 pixels. The voxel size was 0.3 $\times$ 0.3 $\times$ 0.3 mm. The DICOM (Digital Image Communications in Medicine) data was imported into BrainLab ENT 3.0.0 software for surgical planning. All of the drill holes were identified and labeled as targets on the axial, sagittal, and coronal views. The following six anatomical landmarks were identified and labeled as registration point landmark: the left and right infraorbital foramena the anterior nasal spine, the tips of the left and right upper canines, and the mesial contact point of the left and right upper incisors (Fig. 2). Observer 1 performed the surgical planning.

### 2.2. Data collection

The navigation system was set up in a normal dental consultation room to avoid infra-red light interference from other electronic

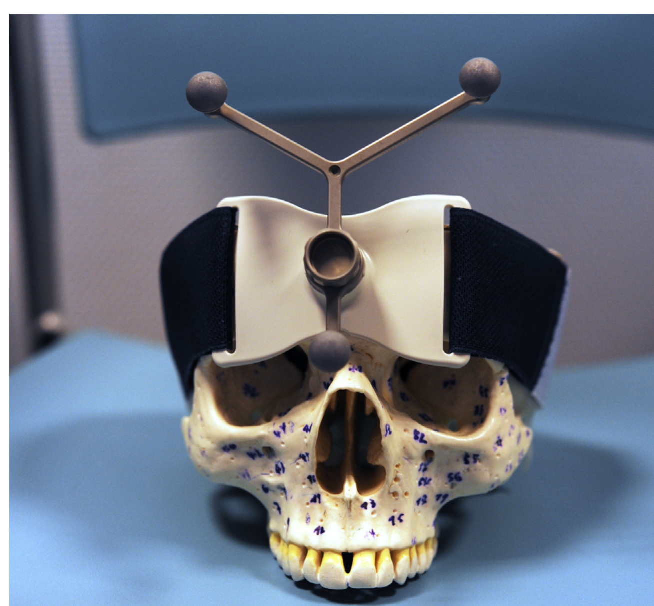

Fig. 1. Eighty-five target landmarks were drilled into the surface of the skull model and numbered. A navigational star array was attached to the surface of the model using a headband.