Application of preoperative registration and automatic tracking technique for image-guided maxillofacial surgery

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\section*{ABSTRACT}

\textbf{Objective:} To investigate the practicality of preoperative registration technique in navigational surgery of facial skeleton.

\textbf{Methods:} Five cases were underwent navigational surgery with the preoperative registration technique. The accuracy of registration process was determined, and the deviation between planning model and postoperative computed tomography (CT) model was detected.

\textbf{Results:} In each case, the preoperative registration was successful for navigational surgery. Preoperative registration and automatic tracking enabled registration free in the operation procedure. The registration precision measured by the system was less than 0.8 mm. The deviation between the intraoperative anatomy and the CT image was less than 1.5 mm.

\textbf{Conclusions:} Preoperative registration technique demonstrates the potential for improved workflow and accuracy in navigational surgery procedures. This technique was found to be particularly advantageous in cases of mandible navigational surgery in which the dynamic reference frame's hard to be fixed.

\section*{Introduction}

Navigational surgery has shown great potential for maxillofacial surgery, particularly when precise location of any instrument or bony anatomic landmark is required.\cite{1-4} Two key problems for navigational surgery are accurate patient-to-image registration and ongoing tracking of patient’s position. Fiducial-based registration is currently available to achieve proper alignment and regarded as ‘gold standard’.\cite{5} Fiducial-based registration relies on anatomical landmarks and/or fiducial markers affixed to the patient’s skin or bone prior to image acquisition. Since surgical procedures usually take place several days after data acquisition, it is inconvenient for the patient to fix with fiducial markers. Inevitably, the actual position of the patient is continuously changing during the surgery procedure. To track patient’s motion, a rigid and invasive dynamic reference frame or cephal-bracket is fixed on the patient's skull. In spite of an established and reliable clinical method, however, it is invasive, tedious, time-consuming and susceptible to errors by the surgeon, which finally resulted in inaccurate navigation.\cite{6}

To address the registration and tracking problems, the authors develop a novel preoperative registration and so-called ‘automatic’ tracking method, which can perform initial patient setup and frequent detect patient motion during surgery.\cite{6} In the present report, we present our clinical application of this preoperative registration technique in the navigational surgery of facial skeleton.

\section*{Methods and patients}

The system includes the following two parts: AccuNavi navigation system (Universal Enterprises Group Co, Shanghai, China) and a preoperative registration and ‘automatic’ tracking device. The device consisted of a customized acrylic-polymer splint and a support frame (Figure 1), which is detailed depicted in preceded report.\cite{6} Basic idea of the preoperative registration is to register the device with the three-dimensional (3D) facial skeleton virtual model, which is acquired with the device fixed on denture (Figure 2). At the beginning of operation, splint with the device was inserted to denture again for detection facial skeleton’s motion...
during navigational surgery. As the four fluorescent balls could be detected by the navigation system, the device could be used as dynamic reference frame and the patient’s position could be automatically tracked during surgery procedure. Some measures were taken to strength the stability of the device. The device consisted of support frame holding together with a titanium plate, which fixed the splints with screws. Before the splint is custom made, a pellet of resin is attached to the buccal surface of canine and first molar, which can add the retaining strength. To minimize the possible deformation of the device, the support frame is made of fiber bar, which is light material. And during the remove or reset the device, it was held carefully on the titanium plate other than the fiber bar.

In our department, we have performed five navigational procedures of facial skeleton with this preoperative registration and ‘automatic’ tracking technique. All five patients provided their written informed consent to participate in this study. One patient underwent anatomic reduction of zygomatic–orbital–maxillary complex fracture fragments, two patients genioplasty and two patients gonioplasty. For the patient of zygomatic–orbital–maxillary complex fracture, the anatomic structures of target area were mirrored from the unaffected side, so desired contour of the affected zygomatic–orbital–maxillary complex could be visualized and virtual reduction could be performed on 3D model. Preregistration of the device was finished before operation. Zygomatic–orbital–maxillary complex fracture was exposed by minimal supraorbital, subconjunctival and intraoral incisions, and the fractured segment reduction was released for reduction. The preoperative registration and ‘automatic’ tracking device was inserted to maxilla denture. Clinical accuracy was checked by touching distinct anatomical landmarks with pointer while verifying location on the navigation system’s display. Then, the fractured segment position was precisely modified with the navigation probe. Once the actual reduction was accurately approximated preoperative plan, internal fixation was applied. For patients of genioplasty and gonioplasty, surgical plans were performed with curve plain cutting tool in grid model (Figure 3). After preoperative registration, the device was inserted to mandible denture and the instrument was navigated to designed location. In order to get the system precision of navigational surgery, the patients were checked by CT scanning one-week postoperative. The facial skeleton was segmented and reconstructed to a 3D point cloud model with use of Mimics software v14.0 (Materialise, Leuven, Belgium). The reconstructed 3D point cloud bone models were then imported in the commercial package Geomagic Studio v10.0 (Research Triangle Park, NC) for processing into 3D surface models. Finally, the 3D surface model was superimposed with planning model.

Results

The splints fixed tightly against to the support frame without loosening. The time for preoperative registration is about 5–10 min. The device was easily fixed and removed for image–date acquisition and for intraoperative use. When the device interfered with the hand piece, it was removed from the denture and reinserted if necessary.

The intraoperative navigation was successfully achieved in these patients. With guidance of the system, the position of surgical instrument or probe was shown on a screen real time (Figure 4). The probe was used not only to navigate deformed contour of the affected side, but also to check desired position to which displaced bone was to be located.

Figure 1. The preoperative registration and ‘automatic’ tracking device consisted of a customized acrylic–polymer splint and a support frame.

Figure 2. Preoperative registration is to register the device with the 3D facial skeleton virtual model before surgery.
Figure 3. Surgical planning of genioplasty were performed with curve plain cutting tool in grid model.

Figure 4. The position of surgical instrument or probe was shown on a screen real time.
With navigation reference, the hand piece was navigated to the cutting margin real time (Figure 5).

In each case, the registration precision measured by the system was less than 0.8 mm (Table 1). Irrespective of movements of the mandible, it took less than one second to ongoing tracking the actual position of the patient, so the navigation system was thought to synchronize with patients’ movement. No significant loss of accuracy was observed during subsequent episodes of navigation or frequent checks against anatomical landmarks. All surgical interventions were uneventful and patients healed without serious complications. After superimposition of planning and postoperative model, the deviations in most part of the interest area were less than 1.5 mm (Figure 6).

**Discussion**

The synchronization of intraoperative position of patient with the virtual reality imaging is the cornerstone of any navigation system. The synchronization is realized through image registration and motion tracking. Firstly, coordinate of the actual patient is registered with virtual reality, either fluoroimages, magnetic resonance imaging (MRI) scans or CT images. Secondly, the orientation and position of patient and instrument are tracked. Real-time relationship between preoperative images and actual surgical anatomy is displayed on-screen. Generally, registration procedures can be differentiated to manual intraoperative registration or automated registration procedures. Manual image-to-world registration typically requires minutes for a clinician or technologist to perform and can be a bottleneck to surgical workflow. Variety of efforts
have sought to automate image-to-world registration. Coleman et al. [8] developed a novel dual-optical coherence tomography (OCT)/video imaging system, which provides automated registration of OCT and dermoscopy, to assess the potential of OCT in measuring the degree of subclinical spread of basal cell carcinoma. Wang et al. [9] proposed an automatic closed-loop 3D image calibration paradigm for displaying undistorted 3D images, which showed satisfactory image registration and image overlay accuracy. Suenaga et al. [10] designed an augmented reality system that enables the surgeon to get the positional relationship between the preoperative image and the actual surgical site. However, these automatic registration technologies are lack of clinical experience. In our clinical study, the registration is performed before surgery. Since ‘registration’ can be performed extraorally, because there are a fixed spatial relation between spheres and registration markers, the motion of patient is detected automatically, which reduces operation time and increase safety. The device fixed on denture allows freedom of movement for the mandible without loss of accuracy of registration. So fiducial implant is not required, which is a significant advantage for the patient.

In clinical application of navigated surgery, the question of accuracy needs to pay close attention. There are different types of errors to characterize the accuracy. The error of determining the positions of the fiducial markers is defined as fiducial localization error (FRE), The FRE is currently available to the surgeon from navigational systems showed as mean deviate after registration. In target registration error (TRE) terminology, ‘target’ is used to suggest that the points directly associated with the reason for navigation. In medical applications, they are typically locations within the interest area. The TRE, which can be evaluated as the Euclidean distance between the position of a target and the probe point in image space when the probe reached the target in world space, was shown on the navigation workstation after registration. Peacock et al. [11] reported the mean error between the points was 0.7 mm (horizontal) and 1.7 mm (vertical) in the posterior mandibular border, 1.2 and 1.7 mm in inferior mandibular border. Zinser [12] assessed surgical precision ranged to 1.67 mm with an interactive image-guided visualization display for computer-assisted orthognathic surgery. Generally, the accuracy of noninvasive system is less than invasive. However, our study showed that the accuracy achieved with the device is comparable to that achieved with bone markers, [13] which has been widely reported to be less than 1 mm, and the intraoperative precision for a patient has been 1.0 to 2.0 mm. The intraoperative precision in this study was less than 0.8 mm and the outcome deviation was less than 1.5 mm, which proved the device was promising for achieving precise and predictable results. The possible factor of error reduction might be the optimal distribution of the fiducial markers near target region. The markers were fixed far from patient head and around it maximizes the probability of detecting even slight differences and permits accurate registration. Another important factor of error reduction was that the device was well fixed to dentition and in the same position during CT scanning and operation proceeding. Its precision ranged from 0.47 mm to 0.70 mm and was previously published by our research group.[6]

Conclusions

In summary, this article presents clinical application of preoperative registration technique in the navigational surgery of facial skeleton. Preoperative registration overcomes many of the obstacles inherent to most navigation systems. An inherent advantage of the preoperative registration is no waste of precious operating room time. Operation and setup of the device is convenient, and general clinical application should be possible. To determine the real benefits of this technique, the conventional method should be included as the control procedure in future studies.

Disclosure statement

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this article.

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