Frameless intraoperative navigation and referencing in maxillofacial surgery—advances and limitations

M. Schneidera,*, U. Eckelta, G. Lauera, V. Hietscholdb

aDepartment of Maxillofacial Surgery, University Clinical Complex of Technical University of Dresden, Fetscherstraße 74, 01307 Dresden, Germany
bDepartment of Radiology, University Clinical Complex of Technical University of Dresden, Fetscherstraße 74, 01307 Dresden, Germany

Abstract

Computer-assisted surgery has found frequent application in oncological and reconstructive surgery of the maxillofacial region. For those indications, important features are a high degree of mobility of the patient’s head during navigation for a comfortable surgical handling and a high precision of the non-invasive referencing for a good surgical outcome. Common methods of reference-giving, such as applying surface skin markers or using anatomical landmarks, have not been proved accurate enough. Furthermore, a head frame is also inapplicable for complex surgical procedures and its use is reserved for computer-assisted endoscopy. In this study, the accuracy of various types of tooth borne reforming tools was assessed under experimental and clinical condition. Using individually manufactured dental mini-plastic splints and impression trays, we developed different methods for simultaneous dynamic patient tracking and non-invasive reference-giving in an experimental setting and in patients. The acquisition of CT data sets was aided by mini-titanium screws with center drive as fiducial markers, whereas for the magnetic resonance imaging (MRI), oil-containing capsules used as markers proved very useful. Each CT data set was recorded 10 times in the lab. In clinical application landmarks were traced repeatedly. Applying mini-plastic splints marked by titanium screws, we achieved a high accuracy of less than 1.0 mm deviation, which is comparable to that achieved via an invasive approach. The experimentally determined accuracy that includes all potential sources of error (CT-data acquisition, process of reference-giving and dynamic tracking) amounts to 0.68±0.63 mm. The studied system configuration proved to offer a sufficient accuracy for indications in the field of maxillofacial surgery. The method will further profit by improving the stability of the construction and specific adaptation of the program software. However, difficulties in drill and instrument calibration are further sources of error. Limitations arise in
edentulous patients where the demanded accuracy can only be achieved by invasively inserted bone markers. © 2001 Elsevier Science B.V. All rights reserved.

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### 1. Introduction

Navigation systems are very useful tools for correlations between preoperatively acquired data sets and the actual instrument positions at the surgical site (Fig. 1). They are rapidly growing in popularity for application in the field of maxillofacial surgery [3].

In preparation of a navigation-supported procedure, the patient’s position needs to be registered. Thereby, the computed data set is correlated with the actual position of the patient. Surface skin markers that are applied to the patient’s skin prior the CT or magnetic resonance imaging (MRI) scan can facilitate this correlation. However, these

![Fig. 1. Dynamic tracking system: A = Camera system, B = Mobile skull with reference, C = Pointer.](image)
markers can shift on the skin easily and uncontrolled. Another disadvantage is that they may not be removed between the CT or MRI scan and the operation. So the preoperative imaging, planning and the operation need to be performed within a close timeframe [1].

Using a computer mouse, the markers get first marked in the recorded data set and then are targeted for by means of a pointer system during operation. Correlation without marker systems as reference givers, only based on anatomical landmarks, proves not accurate enough.

Another approach for the process of reference-giving is the temporary insertion of osteosynthesis screws. Using that method, some of the problems that arise from skin markers can be eliminated. The positioning of the probe head is definite and shifting is ruled out. Yet, the preoperative insertion of osteosynthesis screws into the calotte seems inappropriate for many indications and elective operations in maxillofacial surgery.

Presently, commercially available navigation systems require a rigid immobilization of the patient’s head. Due to that fixation, mobility and, partly, the view of the surgeon are reduced. Nevertheless, dislocation of the head frame during the surgical procedure is not ruled out. The application of a non-invasive head frame (Fig. 2) is limited to only a few indications such is computer-assisted (navigation-supported) endoscopy. By using a non-invasive head frame, the head is relatively mobile but flexibility and view are still strongly restricted.

Fig. 2. Example of a head frame.
We present another method of reference-giving which is based on tooth borne mini-plastic splints. It combines both the advantages of a safe and precise screw marking with a high degree of mobility of the patient’s head during the surgical intervention [2].

2. Material and method

Based on data sets acquired by a CT and MRI scan, preoperative simulation and planning of the surgical procedure is performed. Afterwards, these data sets are also used for the computer-assisted intraoperative navigation of surgical instruments.

Prior to the imaging individual mini-plastic splints (Fig. 3) were manufactured by means of impression trays. Three to five mini-titanium screws with center drive were inserted into these mini-plastic splints. They only cause small artifacts in the data sets and are reproducible. The center drive of the screws is particularly useful for the accurate insertion of the pointer head because it can be easily localized. While designing the plastic splints, attention has to be paid that the screw markers are not inserted too close to adjacent metallic fillings. In such cases, an extension to the vestibulum, a region that is less afflicted with artifacts, is recommended.

Fig. 3. Mini-plastic splint with titanium screw markers (indicated by an arrow).

Fig. 4. Mini-plastic splint with markers used for MRI.
Instead of screws, oil or contrast medium containing capsules are attached to the plastic splint if the data acquisition and navigation is based on a MRI (Fig. 4).

By means of a modified impression tray (Fig. 5), the reference frame is fixed at the maxilla. The displayed impression tray allows both dynamic reference-giving and mobility of the patient’s head.

3. Results

Under clinical conditions, the described reference-giving system based on mini-plastic splints achieved an accuracy of less than 1 mm deviation. The process of
reference-giving was monitored by additional reference markers and anatomical landmarks during operation.

In the experimental study, we investigated the accuracy of the entire navigation process. In order to compare the preoperative planning with the results after operation, an image fusion of the preoperative and postoperative CT scan was performed. For a total of 400 measurements, we determined a mean deviation of 0.68 mm by a standard deviation of ±0.63 mm [6]. The following diagram (Plate 1) displays the individual data.

4. Discussion

The accuracy of navigation systems used for maxillofacial surgery should not exceed 1 mm of deviation in total [2]. With the presented reference-giving system we achieved a high accuracy which is comparable to that achieved by means of an invasive approach [4]. The system proved to be applicable for different imaging modalities, thereby using specific marker systems. Furthermore, the marker system is suitable as a reference system for the image fusion of different data sets. Due to fusion of CT and MRI data sets, it is possible to demonstrate different morphological and functional aspects in a fused data set.

Imaging can be performed independently from the time of surgery since the individually manufactured mini-plastic splint fits accurately into the patient’s mouth and the data is reproducible.

In contrast to surface skin markers as reference-giving system where an invasive fixation of the patient’s head for example in a Mayfield clamp is necessary, the developed system based on mini-plastic splints allows a high degree of mobility during the surgical intervention.

It can also be used in tumor surgery. Following a preoperative radio or chemotherapy, the tumor is resected in its original boundaries according to the pretherapeutical CT data set. Thus, a tumor resection with an appropriate margin of safety is realizable. Individual mini-plastic splints as basis for a non-invasive reference-giving system can be simply and economically manufactured.

It is suitable for most of the indication in the field of maxillofacial surgery. Beyond it, its application in neurosurgery and otorhinolaryngology is recommended.

However, it is not applicable in edentulous patients. In extended prosthetic reconstruction surgery, metallic artifacts may lead to difficulties in marker identification and registration. Additional problems and sources of error arise by a possible instability of the system. Unnoticed loosening of the reference givers may result in incorrect instrument navigation [5,7].

References


