

Comparison of different registration methods for navigation in craniomaxillofacial surgery.

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INTRODUCTION:

Within the last years, navigation systems became more and more common in craniomaxillofacial surgery. These systems offer some features like three-dimensional visualisation of the skull on a screen and virtual planing of instrumentation that can be used for education and training (Cutting 1992; Cutting et al. 1995; Hassfeld et al. 1995; Hassfeld et al. 1997a; Hassfeld et al. 1997b; Marmulla and Niederdellmann 1998, Watzinger et al. 1999; Schramm 2000, Marmulla et al. 2003).

The need for navigated procedures stems from the demand of higher accuracy. An important factor for this accuracy is the method of registration between the image data and the tracking of the patient and the tool. The correlation between the surgical site and the corresponding image data set in the operating room is the most time-consuming non-operative process for the surgeon (Hassfeld and Muehling 2001).

Recent innovations in laser scanning technology provide a potentially useful tool for three-dimensional surface registration in image-guided surgery (Bucholz et al. 2000).

Brain Lab, a company producing navigation systems, has been offering a commercial handheld scanner called z-touch which utilizes surface matching of a preoperative scan and computed tomography images (Saborowski 2001). The z-touch registers about 200 surface points on the patient's face. The precision of the z-touch is reported to range between 1 and 10 mm, which seems to be insufficient for cranio-maxillofacial indications (Raabe et al. 2002). The reason for the large deviation in accuracy of the z-touch has not yet been discussed. Moreover it is not known whether a shift of the patient's skin surface of different tension in muscles of expression when performing computed tomography and during preoperative surface scanning, may lead to an invalid data set correlation for computer assisted navigation. No phantom or cadaveric study will show the soft tissue shift and elicit

whether these shifts cause a significant alteration of the patient's facial geometry and reduce the accuracy in data set correlations. Therefore it was decided to investigate the difference in accuracy in a clinical compared to a experimental setting.

Furthermore the purpose of this study is to evaluate the clinical reliability of three different registration methods. The laser technique using Z-touch from the BrainLAB system was compared with two conventional (paired-point) registration tools like headset and skin markers in clinical craniomaxillofacial procedures as well as in an experimental skull model using image-guided navigation.

METHODS:

Surface registration and infrared-based navigation have been performed with the z-touch Brain LAB system. Z-touch performs an automatic data set correlation based on the patients surface pattern using the periorbital and nasal area. The patients surface pattern is generated from the patients native computer tomography (CT) data set. Data set correlation is done with just one click on the command button in the BrainLAB system (fig. 1 and 2).

In contrast to this new laser technique the conventional registration methods, for example using a head-set or skin markers, require a preoperative CT scan with prefabricated and locally determined markers in order to correlate the CT data intraoperatively.

In an experimental setting, a stable anthropomorphic skull model with prelabeled markers was scanned and registered with laser surface scanning (z-touch, BrainLAB) as well as external marker-based algorithms (skin markers and head-set). The registration protocol was then repeated 60 times (fig 3).

Registration error as well as accuracy were then calculated.

In a clinical setting, totally seventy-two patients with different indications for oral and craniomaxillofacial surgery were planned for image-guided surgery using the same passive infrared surgical navigation system (VectorVision, BrainLAB) and marker based algorithms (skin-markers or head-set).

The best measure to assess the quality of registration and the true application accuracy is the target localizing error, where target represents the surgical field (Maurer et al. 1993, West et al. 2001). In detail application accuracy was assessed by placing the tip of the pointer on the landmark showed in the CT image and compare the position of the tip with the position in reality.

RESULTS:

In the experimental protocol registration with head-set shows the most reliable results with deviation less than 1 mm in 74% versus the skin markers in 42% and the laser scanning (z-touch) in 40%. Within 2 mm deviation rate a accuracy of 94% with the head-set, 92 % with the skin-markers and 86% with the z-touch scanning could be achieved. (Table 1)

During various clinical procedures involving oral and craniomaxillofacial surgery, the best results were shown when registrations were taken with the headset. The headset showed a deviation of less than 2mm in 94%, versus skin markers in 80% and laser-scanner (z-touch) in 68%. (Table 2)

Furthermore when using the head-set for registration it was technical much easier and faster. In other words we seldom saw a breakdown of the computer and much less software failures in order to complete the registration with the BrainLAB software. Although the preoperative planning require more time, using the head-set device. We see a tremendous save of intraoperative time when using the head-set compared to laser scanning with z-touch in the registration process with the BrainLAB system.

Discussion:

The most commonly used method of registration is the paired-point method with artificial fiducials. A series of fiducial-based corresponding points is identified in both image space and physical space, and the computer determines the transformation between the image and the physical space. Although bone-anchored fiducial markers (screws) provide the most reliable and accurate method for surgical registration, adhesive-mounted skin markers (skin-marker or headset) are the method of choice because they do not require an invasive procedure. With this method, an average application accuracy of 2 to 7 mm can be attained (Alp et al. 1998, Golfinos et al. 1995, Hirschberg and Kirkeby 1996, Maurer et al. 1997, Sipos et al. 1996). In most comparative studies, paired-point skin fiducial registration was more accurate than paired-point landmark registration or surface registration. However, this method os associated with additional cost and requires time and resources (Bucholz 1995).

One alternative to paired-point registration, in which corresponding points are matched, surface-based registration attempts to align the contour of a physical surface wiht the corresponding image surface. In most studies, surface registration has been shown to be less

accurate and less reliable than fiducial registration (Bucholz et al. 2000, Helm and Eckel 1998, Sipos 1996)

There are two crucial points to successful surface registration with the z-touch method. First, it is extremely important to avoid any skin movement in the scanning target areas, i.e., around the eyes, forehead, nasion and zygoma. It is mandatory to remove any adhesive material in this region before scanning. Furthermore, laser scanning should be confined to areas where skin is thin and closely follows the bony relief. Second, it is of paramount importance to use high-quality images. Use of retrospective acquired images is attractive and may be an important economic consideration. Therefore the images must be high quality, with a high resolution matrix (256x256), and in thin slices (1-2 mm).

Conclusion:

Although our results show a much better accuracy when using the head-set compared to the registration with the Z-touch. Laser scanning is a very interesting technique with tremendous benefits (low radiation load, fast, native images can be used). We think when using better technical devices, for example advanced laser and better software, surface registration is a very interesting and useful method for craniomaxillofacial surgery in the future.

Figures and Tables:

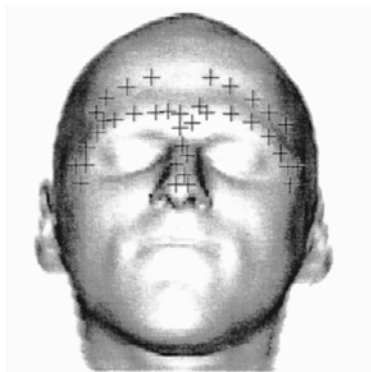


Fig.: 1
Target areas of laser surgery scanning
[z-touch BrainLab]



Fig.: 2
Intraoperative scanning



Fig.: 3
Experimental setting, skull model,
headset and landmarks

| | <i>Number of patients</i> | <i>Deviation < 2mm</i> |
|--------------------|---------------------------|---------------------------|
| Skin marker | 24 | 80% |
| Head set | 24 | 94% |
| Z-touch | 24 | 68% |

Table 1:
Accuracy in the clinical setting (24 patients per group)

| <i>Deviation</i> | | <i>< 1mm</i> | <i>1-2 mm</i> | <i><2mm</i> |
|--------------------|-----|-----------------|---------------|----------------|
| Skin marker | 60x | 42 % | 50 % | 92 % |
| Head set | 60x | 74 % | 20 % | 94 % |
| Z-touch | 60x | 40 % | 46 % | 86 % |

Table 2:
Accuracy in the experimental setting (registration 60x repeated)

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