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Evaluation of two dental registration-splint techniques for surgical navigation in cranio-maxillofacial surgery

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ABSTRACT

Background: Surgical navigation requires precise registration of the pre-operative image dataset to the patient in the operation theatre. Different marker-based and marker-free registration techniques are available, each of them with advantages and disadvantages regarding precision and clinical handling. In this model study, the precision of two dental splint techniques for marker-based registration is analyzed.
Materials and methods: A synthetic full-size human skull was registered with its cone beam computed tomography dataset using (a) a dentally-mounted "rapid" occlusal splint with five titanium screws directly attached to the splint, (b) an "extender", a dentally-mounted occlusal splint with similar fiducials fixed to an extension of the splint. The target registration error was measured for 170 landmarks distributed over the viscero- and neurocranium in 10 repeats per splint type using the Vector Vision^2 (BrainLAB AG, Heimstetten, Germany) navigation system. Statistical and graphical evaluations were performed per anatomical region.
Results: In the periorbital region, the rapid splint, with an average deviation of 1.50 mm (SD = 0.439) showed greater accuracy than the extender with 1.76 mm (SD = 0.525). The viscerocranial results for both splints were similar (extender 1.84 mm, SD = 0.559, rapid occlusal splint 1.86 mm, SD = 0.686). In the cranial vault region, registration with the extender (2.33 mm, SD = 0.685) proved to be more precise than with the rapid splint (2.86 mm, SD = 0.929).
Conclusions: Due to the more compact dimension of the rapid occlusal splint, errors close to the splint were smaller compared to the extender technique. The advantage of greater distances between the registration fiducials on the extender is particularly important in areas such as the orbital roof, the cranial vault, and the lateral skull base.

1. Introduction

The complex three-dimensional (3D) geometry and the requirement of precise symmetrical reconstruction are major challenges for reconstructive maxillofacial surgery. Pre-operative planning with a rapid prototype based on a multi-detector computer tomography (MDCT) scan or on a cone beam CT (CBCT) is a time-consuming and costly approach (Hassfeld and Muhling, 1998). Even if the exact planning based on a patient specific model offers many advantages, it often fails to precisely transfer the planning to the complex craniofacial anatomy. Computer-assisted surgical navigation can be of help for pre-operative planning based upon different radiological datasets and has become a common method in craniofacial surgery (Hassfeld et al., 2000; Yeshwant et al., 2005a, b; Ritter et al., 2006; Luebbers et al., 2008) The most important aspect for technically precise intra-operative navigation is the correct registration of the image dataset of the patient (Marmulla and Niederdellmann, 1998; Marmulla, 1999; Luebbers et al., 2008). The exact registration has a direct bearing on the accuracy of all subsequent navigation tasks (Eggers et al., 2006). The structures established pre-operatively by means of a CBCT or an MDCT are transferred to the patient during registration (Hassfeld and

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Muhling, 2000; Gellrich et al., 2002; Schmelzeisen et al., 2002; Marmulla et al., 2004b; Schmelzeisen et al., 2004; Hohlweg-Majert et al., 2005).

Registration can be subdivided into distinct groups. One differentiates between marker-based (Altobelli et al., 1993; Hassfeld et al., 1995; Howard et al., 1995; Schramm et al., 1999; Luebbers et al., 2008) and marker-free (Troitzsch et al., 2003; Marmulla et al., 2004a; Hoffmann et al., 2005; Marmulla et al., 2005b) registration techniques. In the case of marker-based registration, the markers have to be in the patient prior to the establishment of the dataset in an inter-operatively solid and accessible position. For instance, the markers may be titanium screws (Sinikovic et al., 2007; Luebbers et al., 2008; Lubbers et al., 2011c) placed at clear, easily detectable bone structures during surgery.

In addition, markers may be fitted on a splint fixed to the maxillary teeth (Schramm et al., 2001) or self-adhesive markers may be glued to the skin (Alp et al., 1998; Hardy et al., 2006).

In the case of marker-free point-to-point registration, easily detectable, marked anatomical structures (Swennen et al., 2006; Lubbers et al., 2010, 2011b; Sun et al., 2012) that must also be discernible on the sectional views of the dataset are used. Another marker-free registration is laser surface scanning, which matches random points on the skin surface to the soft tissue data of the radiological dataset (Grevers et al., 2002; Marmulla et al., 2004a, b; Hoffmann et al., 2005; Marmulla et al., 2005a, b) For technical reasons, the data obtained by cone beam CT is relatively unsuitable for this surface matching technique.

Each of these registration methods is subject to error. The present study compares (van den Elsen et al., 1982; Maciunas et al., 1994) the registration methods of two different splints (a "rapid" occlusal splint, Fig. 1, and an extender, Fig. 2). The accuracy of measurement is separately assessed for three anatomical regions (orbital, maxillary, and cranial). Earlier studies have already dealt with this topic (Luebbers et al., 2008; Bettschart et al., 2012). They showed that using additional titanium screws directly attached to the skull can optimize the registration via splints. The present study intends to evaluate possible optimization when a purely splint-based registration is utilized. In addition the "rapid" occlusal splint, which offers decisive clinical advantages, is evaluated.

2. Materials and methods

Ten series of measurements were taken in vitro on a synthetic human skull model (A20, 3B Scientific, Hamburg, Germany) using the optical navigation system Vector Vision^2 (Brainlab AG, Feldkirchen, Germany).

Fig. 1. Skull model with mounted rapid splint.

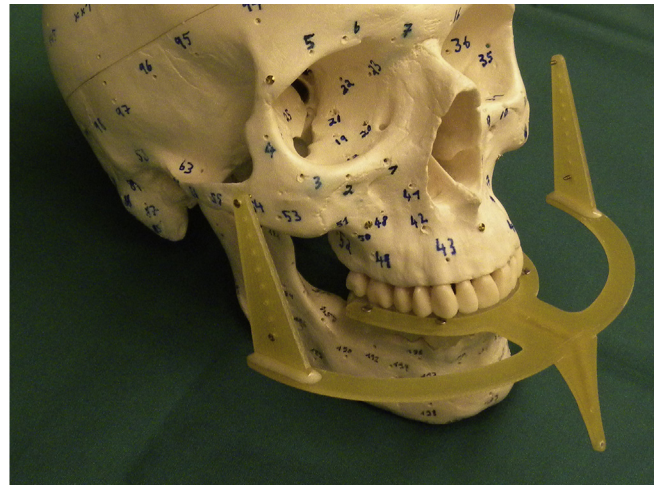

Fig. 2. Skull model with mounted extender. The 170 drilled landmarks for regional precision are numbered.

2.1. Splint preparation

For the rapid occlusal splint (a) a prefabricated splint that carried the necessary fiducials for point-to-point registration was individualized with impression material directly on the skull model. The splint was then removed from the model and any interfering material was removed until precise and stable repositioning of the splint was easily possible (Fig. 1). Overall, the approach was similar to clinical situations involving acute trauma patients (Lubbers et al., 2011a).

For the extender, an occlusal splint with extension, an impression was taken from the skull model. An occlusal splint was thermoformed on the plaster model. To this splint a light extension made of glass fibre-reinforced plastic was mounted, which then carried the registration fiducials. To achieve necessary stiffness, the construction was reinforced with two carbon fibre tubes (Fig. 2).

2.2. Model preparation

The same synthetic human skull model that had been used in the previous paper by our group (Luebbers et al., 2008; Bettschart et al., 2012) was used to allow direct comparison of the measurements. The 170 drilling holes were distributed over the entire visero- and neurocranium; each one had a diameter of 1.2 mm. The skull was scanned with a high-definition CBCT (KaVo 3D eXam, Kavo Dental GmbH, Biberach/Riss, Germany). A resolution of $0.4 \times 0.4 \times 0.4$ mm was set for the image and the skull was placed in such a way as to enable a full representation, including the splint in one dataset. The DICOM data was subsequently imported into the Brainlab iPlan ENT 2.6 (Brainlab AG, Feldkirchen, Germany) software. All of the drillings and the centre of the screws/fiducials fixed to the splints were tagged as shown in Fig. 3. The individual landmarks, as well as the screws, were identified manually on the coronal, sagittal, and axial views as well as by 3D projection. The use of tenfold magnification ensured maximal precision. The final datasets were fed into the navigation system via a USB drive.

2.3. Image registration and surgical navigation

The navigation system was setup in a room under daylight conditions that had been partially darkened in order to avoid, as much as possible, interference from ambient light. The lighting was similar to that of a standard operating theatre. A reference star was