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Research Paper
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Implant-oriented navigation in orbital reconstruction. Part 1: technique and accuracy study

R. Schreurs[1,2], L. Dubois[1], A. G. Becking[1], T. J. J. Maal[1,2]
[1]Department of Oral and Maxillofacial Surgery, Orbital Unit, Academic Medical Centre of Amsterdam, University of Amsterdam, Academic Centre for Dentistry (ACTA), Amsterdam, The Netherlands; [2]Department of Oral and Maxillofacial Surgery, Radboud University Medical Centre, Nijmegen, The Netherlands

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Abstract. Intraoperative navigation is frequently used to assess the position of the implant in orbital reconstruction. Interpretation of the feedback from the navigation system to a three-dimensional position of the implant needs to be done by the surgeon, and feedback is only gathered after the implant has been positioned. An implant-oriented navigation approach is proposed, with real-time intuitive feedback during insertion. A technical framework was set up for implant-oriented navigation, with requirements for planning, implant tracking, and feedback. A dedicated navigation instrument was designed and a software tool was developed in order to meet the technical requirements. An accuracy study was performed to investigate the accuracy of the method in comparison to the regular navigation pointer. A proof of concept was provided. The results showed a translation error of 1.12–1.15 mm for implant-oriented navigation with regular registration (pointer 0.71–0.98 mm) and 0.81 mm with accurate registration (pointer 0.54 mm). Rotational error was found to be small (<3°). Quantitative and intuitive qualitative feedback could be provided to the surgeon in real-time during insertion of an orbital implant. Following this proof of concept and accuracy study, the implications for the clinical workflow should be evaluated. An implant-oriented approach may form the foundation for augmented reality or robotic-aided implant insertion.

Key words: intraoperative navigation; orbital reconstruction; orbit; real-time; feedback.

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Intraoperative navigation is a tool that is frequently utilized in orbital reconstruction to verify that the reconstruction has been performed according to plan[1–9]. The position of the tip of the navigation pointer is visualized in real-time and can be used to assess the position of the implant in the orbit after positioning[10–12]. The information is presented to the surgeon in multiplanar views corresponding to the current position of the navigation pointer; the contour of the restored orbit is evaluated. This gives rise to quickly altering views if the pointer is moved over the contour of the orbital implant. This may hamper accurate assessment of the implant position in three dimensions[13], since the implant position has to be deducted from the contour feedback in the multiplanar views.

Navigation markers and rulers have been proposed to improve the assessment of implant position with navigation[13–15]. The rulers and markers comprise an approach more oriented to the position of the implant itself: instead of contour feedback in the multiplanar views, the feedback is provided from fixed points or trajectories embedded in the implant design. The relationship between the current position of

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the navigation pointer in the marker and the planned position of the marker is visualized; the distance between the actual and planned position of the marker is provided as quantitative feedback to the surgeon. This method provides a more intuitive feedback on the position of the implant in three dimensions[13,15]. Quantitative evaluation of this feedback method in relation to implant position has shown an improvement in implant position over feedback from the multiplanar views[13].

The interpretation of the navigation feedback to a three-dimensional (3D) position of the implant still needs to be done by the surgeon. Based on feedback from the marker points on the implant, the surgeon has to establish the desired rotational and translational movement of the implant in order to move it to the planned position. Another drawback of current navigation is that the feedback is provided after implant positioning. While the tip of the pointer is tracked in real-time, feedback from the implant position can only be gathered after positioning the implant and not during insertion of the implant.

The clinical goal is to overcome the drawbacks associated with current navigation concepts, which hamper intraoperative assessment of implant position and may lead to suboptimal implant positioning in orbital reconstruction. A novel navigation approach for orbital reconstruction is presented here, which provides real-time navigation feedback for an orbital implant during insertion. The implant is tracked during insertion, and feedback about the 3D orientation of the implant in relation to the planned position is provided intuitively. In this study, the technical background of this concept was tested and the accuracy of the system as a whole was compared to the accuracy of the navigation pointer used in the conventional navigation approach, in a laboratory set-up.

Materials and methods

Technical background

Four requirements need to be met for real-time navigation of an orbital implant: (1) the virtual planning, including the patient's coordinate system from the DICOM data and planned position of the orbital implant, should be available outside the navigation system; (2) the current position of the implant should be tracked continuously and be available outside the navigation system; (3) the current position of the implant should be expressed in relation to the planned position of the implant; (4) instructions should be provided by a dedicated software application.

Virtual planning data

The computed tomography (CT) data of a patient who had been operated on for an orbital fracture in the Department of Oral and Maxillofacial Surgery of the Academic Medical Centre of Amsterdam were used in this study (CT head protocol, 120 kV, 160 mAs, pitch 0.9, collimation 20×0.6 mm, field of view (FOV) 249 mm, matrix size 512×512, slice thickness 1 mm, slice increment 1 mm). The DICOM data were loaded into the Brainlab planning environment (iPlan 3.0.5; Brainlab AG, Feldkirchen, Germany). A stereolithography file (stl) of a preformed orbital implant was provided by the manufacturer (KLS Martin, Tuttlingen, Germany). This was imported as a model into the planning environment and was positioned in the optimal position for reconstruction of the orbital defect. Through the 'stl export' functionality, a virtual model of the implant in the planned position was generated. The planning was imported into the Kolibri navigation system (Brainlab AG). If the IGT Link connection is made available on the Kolibri device, communication between the Kolibri and an external device (laptop) is possible via an ethernet connection. The 'Open IGT Link' protocol allows a tracking data stream to be set up between the Kolibri system and the external device[16], thus the tracking data can be processed on the external device.

Tracking the implant position

An instrument that inserts the implant was developed. The following requirements had to be met in terms of the instrument and its relationship to the position of the implant: (a) the reflective markers on the instrument should be visible at all times during insertion; (b) the geometry of the reflective markers on the instrument should be known to the system, in order to remove the need for the instrument to be calibrated every time it is used; (c) a rigid attachment should exist between the instrument and the implant, with a known relationship between the instrument position and the implant position; (d) the instrument should not hamper fixation of the implant.

The Kolibri system recognizes several geometries of reflective markers belonging to certain standard Brainlab instruments, which do not have to be calibrated before use. One example is the geometry associated with the navigation pointer. These instruments are defined in the 'precalibrated instrument' (.pci) files on the Kolibri system. The position of these instruments is expressed in the tracking data stream set up between Kolibri and the external device as a mathematical expression of the rotation and translation of the instrument (transformation matrix). Choosing a geometry for instrument markers that is similar to a known instrument geometry should allow easy interpretation of the tracking data provided by the system.

Relating implant position to planned position

Relating the current position of the implant to the planned position is necessary in order to provide turn-by-turn feedback in terms of the rotational and translational movements needed to acquire the planned position. This requires setting up a reference frame for the implant itself. In a previous study, a reference frame was proposed to quantitatively assess the acquired position of the implant[17]. A similar positioning frame was set up for the implant used in this study, as shown in Fig. 1a. As stated in the previous study, the orbital implant positioning frame fulfils the requirement that the current position of the implant can be related to the planned position of the orbital implant at any time, making real-time feedback possible.

Software design

The aim of the software is to receive the tracking data from the navigation system, process the data to rotational and translational measurements, and visualize it in an intuitive fashion, all in real time. The first step should be to import the virtual model of the planned implant. This model should be aligned to the reference position of the implant in the orbital implant positioning frame, so translations and rotations can be expressed on the basis of the implant in the reference frame from Fig. 1a. After the registration procedure for intraoperative navigation is completed, an IGT Link connection should be established with the Kolibri. This will ensure that tracking data from the instrument can be received by the software and that the implant position can be calculated. A systematic overview of the transformations (mathematical expression for rotation and translation) involved in the process is provided in Fig. 2.