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Determination of error sources and values for an individually mouldable surgical targeting system

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Keywords Surgical template · Micro-stereotactic frame · Image-guided surgery · Cochlear implantation

Purpose

Highly accurate drilling of bore holes in bone, as well as positioning surgical tools or stimulation probes with submillimetre accuracy requires assistance devices to support the surgeon in performing these exacting tasks. Recently, we introduced a new concept for a surgical targeting system [1], which includes a surgical template ('jig') mouldable in a patient specific manner using bone cement (Fig. 1). Individualization of that template should be performed by the surgeon and its team inside the operation room using a manually operated alignment device (called 'Jig Maker'). Aim of this work is to provide insight into the major factors contributing to inaccuracies with special focus on the manual operation of the Jig Maker.

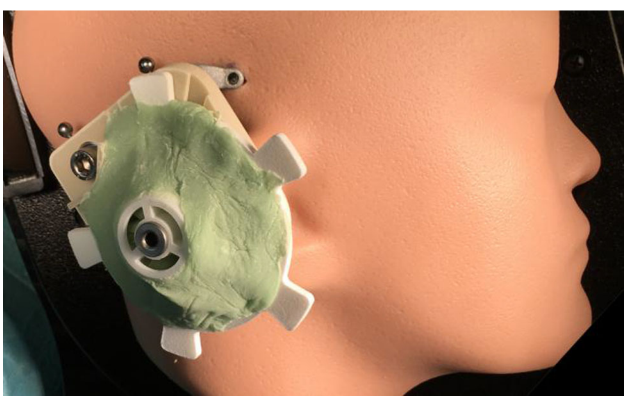

Fig. 1 Surgical targeting system fixed to a half-skull phantom with artificial skin. The drill bushing guides surgical tools, in this study a twist drill bit, strictly along the planned trajectory. The patient-specific configuration is secured after hardening of the bone cement

Methods

In the first part of the study the intra-operator reliability was investigated. For that purpose the same configuration of the hexapod-based Jig Maker (Fig. 2) was adjusted ten times by the same user. The resulting configurations of the Jig Maker were measured using a portable coordinate measuring machine (CMM, Romer Absolute Arm Compact 7312, Hexagon Manufacturing Intelligence, Wetzlar, Germany). The standard deviation of these measurements was calculated, which is referred to as user error ε_{user} in the following.

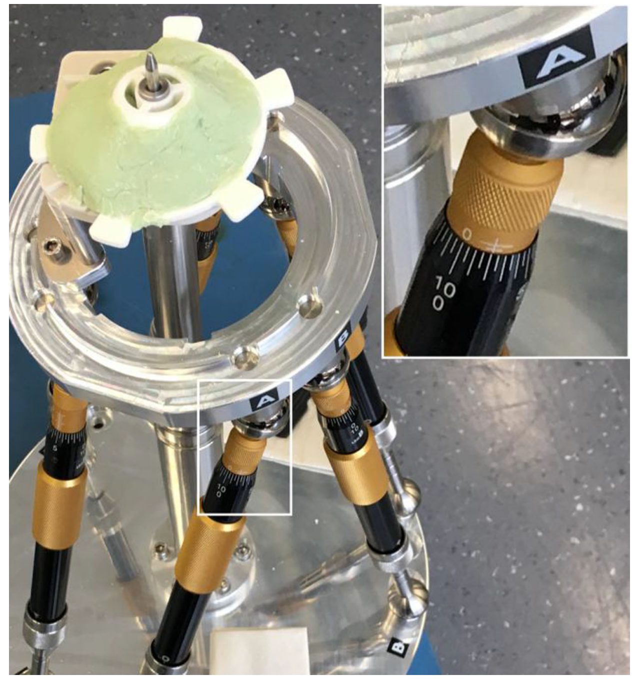

Fig. 2 The Jig-Maker with the surgical template on top of the upper platform. Adjusting the length of all struts enables pose-setting with respect to the alignment pin in the central axis of the device, which represents the planned trajectory

In the second part, half-skull phantoms (Sawbones Europe AB, Malmö, Sweden) made of bone-substitute material and artificial skin (in order to simulate the whole surgical workflow [2]) and corresponding computed tomography (CT) images were used to plan and drill ten bore holes running down to the approximate location of the inner ear. A bone-anchored, unique reference frame ('Trifix') served for both image-to-patient registration after CT imaging and rigid fixation of the surgical template to the artificial skull (Fig. 1). For each trajectory the corresponding lengths of all six struts of the Jig Maker were calculated, afterwards set and finally controlled. After length setting, the struts of the Jig Maker were measured again using the portable CMM in order to get insight into which inaccuracies of the final jig were contributed by the kinematic of the Jig Maker (e.g. manufacturing tolerances) and also the users interaction. This error caused by imperfectly adjusted struts is referred to as ε_{struts} in the following.

Afterwards, the surgical template was fabricated (Fig. 2) and, after hardening of the bone cement, it was mounted on top of an accuracy test bench [1] in order to determine the positioning error (ε_{pos}). Finally, the template was fixed to the reference frame still attached to the artificial skull (Fig. 1) and the initially planned hole was drilled. A second CT scan was used to compare the actual position of the drill canal with the desired one at the target point (ε_{total}).

Results

The precision of the manual length setting of the struts was found to be ε_{user} = 0.04 mm, which is in the range of the accuracy of the CMM (± 0.025 mm). The mean strut length setting error ε_{struts} was (− 0.09 ± 0.09) mm, which indicates a systematic error in the kinematic of the hexapod. However, we also detected a maximum error of 0.65 and 0.35 mm for one single strut in trial #2 and #10, respectively. Reviewing the photo documentation of the adjusted legs showed that these errors stem from a mix-up of two digits when setting the micrometre screw. The mean positioning error ε_{pos} at the target point was found to be 0.35 mm with a standard deviation of

0.09 mm for all ten experiments. In case of the drilling in artificial bone material, the planned target point was reached with a deviation (ε_{total}) of (0.35 ± 0.30) mm.

Conclusion

Manual length setting is feasible with high precision; however, the current design of the hexapod's leg with an integrated micrometre screw is a source of individual errors. In order to increase patient's safety additional security measures (e.g. multi-user readings, sensors) are desirable to detect fatal errors in manual length setting before the surgical template is built. Based on the results the calibration of the Jig Maker was improved which significantly decreased the strut length setting error to (0.01 ± 0.09) mm. This improved calibration will be used in following studies.

Acknowledgment

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Endoscopic neurosurgery using operation supporting robot "iArmS": preliminary clinical application

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Keywords Neurosurgery · Endoscopic neurosurgery · iArmS · Robotic surgery

Purpose

As neurosurgery takes a relatively long time and requires delicate manipulations, hand tremble among neurosurgeons becomes a considerable obstacle to precise microneurosurgery. To resolve this problem, the operation supporting robot (intelligent arm support system "iArmS®", DENSO Corporation, Kariya, Japan) has been developed cooperated with medical-engineers. This revolutionary motor-less medical robot was designed to support the surgeon's forearm to prevent hand trembling and alleviate fatigue during microneurosurgery. It follows and fixes the surgeon's arm at an adequate position automatically. Here, we report the application of this robotic device in endoscopic neurosurgery including endoscopic endonasal approach (EEA) and endoscopic intraventricular surgeries (EIVS), along with an evaluation of our initial experiences.

Methods

The study population consisted of 43 patients with pituitary adenoma ($n = 29$), meningioma ($n = 3$), Rathke's cleft cyst ($n = 3$), craniopharyngioma ($n = 2$), chordoma ($n = 2$) and others ($n = 4$). All patients underwent surgery via the EEA with a rigid endoscope. During nasal and sphenoid phases, iArmS® was used to support the surgeon's non-dominant arm that held the endoscope (Fig. 1). Besides, four patients underwent EIVS including endoscopic third ventriculostomy with flexible endoscopy. To perform EIVS easily, in which the angle of the surgeon's elbow is different from that in EEA and microscopic neurosurgery, a special distinctive attachment (ARIZONO ORTHOPEDIC SUPPLIES CO., LTD., Kitakyusyu, Japan) that fits between robotic arm and handstand, has been developed. This study has evaluated the effectiveness of robotic devices in EEA and EIVS (with special attachment) based on the surgeon's subjectivity. The surgical outcome including tumor removal rate, complication rate, operative time and blood loss were not included in this study.

Fig. 1 Intraoperative photograph showing endoscopic endonasal transsphenoidal surgery during the nasal phase with iArmS®. The system supports the surgeon's non-dominant hand, which holds the endoscope

Results

We used iArmS® easily due to the sufficient knowledge of its characteristics and the familiarity with its manipulation before surgery. The iArmS ® followed the surgeon's arm-movement automatically. It reduced the surgeon's fatigue and stabilized the surgeon's hand during the EEA. Shaking of the video image decreased due to the stabilization of the surgeon's scope-holding hand with iArmS®. There were no complications related to the usage of iArmS®. Although, the fatigue reduction of the surgeon's arm may lead to improvement of the surgical outcome indirectly, it seems to be difficult to prove the direct effectiveness of iArmS® for EEA with a preliminary and initial experience-based study. The iArmS® was also utilized for EIVS due to development and application of special attachment as well as the EEA.

Conclusion

The details of the iArmS® and clinical results were presented and we reported our initial experience with iArmS® in endoscopic neurosurgery. The iArmS®, which is considered a breakthrough operation support robot, enables both stability of the surgeon's hand and excellent operability not only in microsurgery but also endoscopic neurosurgery. Sufficient knowledge of the characteristics of iArmS® makes it a useful new modality for EEA and EIVS. It is expected that it will lead to the development and widespread application of robotic neurosurgery. While robotic platforms have the potential to greatly enhance the performance of endoscopic neursurgery, there is a strong rationale for research into next-generation robots that are better suited to endoscopic neurosurgery. Continued advances in not only surgical technique and instruments but also robotics will ensure continued brisk evolution in this expanding field.