Acetabular cup navigation using patient-specific guide and inertia sensors

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Introduction: Acetabular cup malalignment is associated with diverse complications such as polyethylene wear, impingement and increased dislocation rate. Computer-assisted methods have shown to be able to improve the accuracy of cup alignments, but are difficult to use, require additional equipment in the OR and have time-consuming registration procedures. The goal of this project was to develop an easy-to-use navigation procedure requiring minimal equipment for acetabular cup alignment. The project was divided into two parts:

- Development of a method for registration of the acetabulum using a patient-specific guide, and testing of the accuracy and precision of this method in an in-vitro cadaver trial.

- Development of a method for intraoperative guidance of the impactor using inertia sensors, and testing the feasibility of the proposed method in a clinical trial case.

Materials

Part 1: A preoperative CT scan of the hip was obtained, a 3D model of the acetabulum was created, the pelvic plane determined and the cup orientation planned. A registration area, which included the accessible part of the acetabular fossa and the surrounding articular surface, was chosen for the individualized guide. A guidance cylinder, aligned along the planned cup orientation, was attached in the center of the guide (Figure 1a). Since the selected registration area is often lacking a sufficient number of distinct registration features, we designed an intraoperative verification method. To verify the position of the individualized guide, a sleeve was designed to slide over the central cylinder (Figure 1b). An attachment on the central cylinder allowed this sleeve to lock in an exact position. The sleeve corresponds to a segment of the acetalular rim and, a) Registering of the patient-specific guide; b) Applying of the verification sleeve; c) iPhone in holder is positioned on registered patient-specific guide and the target alignment is defined; d) Impactor with attached iPhone; e) Graphical User Interface to navigate the impactor alignment. If the electronic “bubble” is centered, the target alignment is reached.

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Once it is slid down into position, verifies the orientation of the individualized guide.

To measure the accuracy of the proposed registration method, we performed an in-vitro trial on three fresh-frozen hemi-pelves. Seven participants registered a patient-specific guide for each cadaver, verified the position using the method described above and if necessary, corrected the position of the guide. During the trials, an optoelectronic camera was installed in the laboratory, sensors were attached to all hemi-pelves and all individualized guides and a registration was performed for each object. After the initial registration of the patient-specific guide to the acetabulum, the guide position was recorded with respect to the acetabular coordinate system. This procedure was repeated after the participant verified and corrected the position of the guide.

The recorded values were evaluated and statistically assessed.

**Part 2:** To transfer the planned alignment information from the registered guide to the impacting of the cup, we developed an intraoperative guidance method based on inertia sensors. For this specific trial we used a three axes linear accelerometer (STMicroelectronics, GENEVA, Switzerland) integrated in an iPhone 3G and the iPhone application iHandy Carpenter (iHandySoft Inc.).

We designed a holder to align the iPhone orthogonal to the central cylinder of the patient-specific guide (Figure 1c). In this position we recorded the alignment of the iPhone as the target alignment. The iPhone and the patient-specific guide were removed and the surgeon performed the reaming of the cup in the conventional way. A specially-designed attachment for the impactor was developed to fasten the iPhone orthogonal to the axis of the impactor (Figure 1d). A graphical user interface on the iPhone (Figure 1e) helped the surgeon align the impactor to the saved target alignment.

We tested the feasibility of the proposed method in a clinical trial. Two weeks before the surgery, a CT scan of the patient’s hip was obtained and the acetabulum model created. The surgeon planned the cup orientation with 45° anteversion and 20° inclination. A patient-specific guide was created as described in Part 1.

Intraoperatively, the iPhone was packed in a sterile bag and mounted in the holder. The surgeon then performed the above method for registering the acetabulum, defining the target alignment and navigating the impaction of the cup.

Postoperatively, X-rays were used to measure the anteversion and inclination of the cup.

**Results:**

**Part 1:** The deviation between the planned and registered inclination averaged 4.14° (StDev 6.6) before the verification was performed. After the participants applied the verification methods, the average inclination error was 3.01° (StDev 5.7).

In anteversion, we measured an average error of 4.99° (StDev 3.5) before, and 4.33° (StDev 2.8) after the verification was performed.

**Part 2:** The radiographic measured angles in the clinical trial were 45° anteversion and 25° inclination.

**Discussion:** The registration of an acetabulum using an individualized guide has many challenges due to insufficient accessible distinct registration features. Furthermore, segmentation of an osteoarthritic hip is often error-prone due to limited joint gaps and osteophytes. These challenges were reflected in our results of the in-vitro accuracy test with initial registration errors of 4° inclination and 5° anteversion. However, the use of the proposed verification method could reduce these errors to 3° inclination and 4° anteversion. The verification method also had a positive effect on the standard deviations, which suggests that it increased the accuracy and precision of the registration.

After successful registration of the acetabulum, the remaining challenge was to transfer the planned cup alignment to the surgical impacting of the cup. Since this navigation problem could be reduced to two
rotational angles, we decided to use inertia sensors. These sensors are easy to use and require only a minor addition of equipment to the surgical workflow.

A disadvantage of the proposed method is that it requires the hip to remain still between the registration and impacting. In a new development, we solved this problem by mechanically navigating a 4mm Shantz pin placed in the ilium outside the acetabulum, which can be used to re-calibrate the accelerometer before component impaction to account for patient movement.