An Original Study

Accuracy of an Image-Guided Navigation System for Pelvic Surgery Based on a Multimodality Registration Object: A Cadaver Study

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Abstract

Accurate registration of external landmarks is often required for computer-aided surgery. In the study reported here, we investigated the influence of a new externally fixated multimodality registration object (MRO) on the accuracy of an image-guided navigation system in a human cadaver pelvis. With the MRO placed on the ipsilateral anterior superior iliac spine (ASIS), 14 of 17 target points showed a mean deviation (1.1 mm) that was significantly lower than that registered with the MRO on the contralateral ASIS (2.5 mm). In addition, the distance of target points from the MRO and the deviation of target points were highly correlated. This MRO provides a feasible means for achieving improved registration in computer-aided surgery of the pelvis.

Because of anatomical conditions, the surgical approach of targets such as tumors and osteotomy starting points in the pelvis is a complex challenge. Computer-aided surgery (CAS) is intended to improve the effectiveness of surgery in the pelvis and reduce incision size and tissue damage. Non-navigated operations in the pelvis often involve large approaches and resections.[1] Imageless navigation systems use the frontal pelvic plane or other bony landmarks for reference. However, soft tissue, including skin, subcutaneous fat, and muscles, might render these methods inaccurate.[2] In spinal surgery, image-based navigation systems that use bony landmarks (eg, spinal processes) for reference are associated with similar problems.[3] In addition, in contrast to vertebral bodies with easily identifiable small anatomical landmarks, the bone structure of the pelvis lacks such clearly demarcated bony features.

One of the most significant and error-prone steps in navigation is registration.[3] For the study reported here, we developed a multimodality registration object (MRO) and combined it with an image-guided navigation system. Tests were performed on a human cadaver pelvis to investigate the accuracy of the image-guided navigation system based on the MRO to determine whether the mean deviation with the MRO placed on the same half of the pelvis as the target screws would be lower than that reported by other investigators using other registration methods.[4]

"...our MRO appears to offer more effective registration than does the method of using bony landmarks."

Materials and Methods

For this cadaver study, we used an image-guided navigation system (Stryker Navigation System, Version 1.05; Stryker Leibinger, Freiburg, Germany) equipped with an optical localizer, active battery-powered trackers, an active pistol grip pointer, a stainless steel monocortical screw (navigation pin) to hold the MRO, a computer, and a monitor. The optical localizer, which consists of 3 boom-mounted infrared cameras, tracks the infrared signals of the trackers, which are equipped with light-emitting diodes. The surgeon uses the pointer to operate the software and digitize reference points. The instruments and the bony structures are displayed as virtual objects in real time on the monitor. The system software runs on a standard laptop (Dell Latitude, Microsoft Windows NT 4.0).

The tests were performed on a human cadaver pelvis that had 34 titanium screws (diameter, 2 mm; length, 7.5 mm)

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Figure 1. Multimodality registration object (length, 8 cm; width, 8 cm).

Figure 2. Digitization of target points with navigation software in axial, sagittal, and coronal views and in 3-dimensional reconstruction. In this case, target point 11 was approached.

Figure 3. Titanium screws (diameter, 2 mm; length, 7.5 mm) with navigation marker (left: diameter, 5 mm; length, 7 mm) and computed tomography marker (right: inner diameter, 6 mm; outer diameter, 9 mm).

inserted. These screws served as landmarks of the relevant anatomy of the cadaver pelvis, including acetabulum, iliac crest, ala of sacrum, pubic crest, pubic tubercle, iliac spines, ischial spine, iliac fossa, superior and inferior ramus of pubis, superior and inferior ramus of ischium, body of ischium, and surrounding bone of foramen obturatum. The screws were placed mirror-inverted into both halves of the pelvis. Thus, 17 screws were inserted in each half of the pelvis. Before computed tomography (CT) scans were obtained, special CT markers with spherical heads consisting of polycarbonate (inner diameter, 6 mm) were plugged onto these screws.

used titanium navigation markers (length, 7 mm) instead of CT markers. The centers of the CT markers and the navigation markers were exactly the same (Figure 3). The navigation markers had cone-shaped heads, which enabled the navigation pointer with a spherical head to fit exactly into the center of the navigation markers, irrespective of the position of a marker on the pelvis.

The cadaver pelvis was placed in the supine position without fixture, and the MRO was mounted first into the right ASIS. For registration, all 4 MRO markers had to be approached. Two independent observers manually approached 17 screws in the right half of the pelvis in a predefined sequence (Figure 4). After 20 measurement trials by each observer, the MRO was switched to the left ASIS, contralateral to the location of the pelvic targets, and again 20 trials were performed by each observer. The same sequence of measurements was maintained for the left side of the cadaver pelvis. The deviation (in millimeters) of each digitized reference point and each digitized target point was recorded.

"Advantages of the MRO are that the patient can lie in either a supine or lateral position, and the method can be used in any region of the human body."

For registration, we developed the MRO and fixed it onto a navigation pin introduced into the anterior superior iliac spine (ASIS). This MRO contained a Plexiglas plate on which 4 divergent standard screws and a navigation tracker (Stryker Leibinger) were inserted (Figure 1). The screws were used for registration, and the navigation tracker interacted with the navigation system by way of light-emitting diodes.

Two CT scans of the entire pelvis were obtained at 82 kV, 100 mA, 0.8 second of rotation, a 47.5° defined field of view, a noise index of 16, and 1.25-mm slice thickness. The CT scanner was a General Electric LightSpeed 16 (GE Healthcare, Waukesha, Wis).

The MRO was placed on the left ASIS for the first CT scan and on the right ASIS for the second CT scan. The CT data were fed into the navigation system. To determine the position of the center of the CT marker, we defined the target points using Stryker Neuro System software (Version 1.1-9) on a standard laptop (Figure 2).

For the navigation measurements to be described, we

Statistical analysis was done with SPSS Version 15.0 (SPSS, Chicago, Ill). As variables were not normally distributed, nonparametric tests were used throughout the study. The Mann-Whitney U test was used to analyze differences between ipsilateral and contralateral measurements. Results are expressed as means and SDs. The α level of each test was adjusted downward to ensure that the overall risk for several tests remained 0.050—a correction done with the Bonferroni method. For the reference points (R1-R4), $P<.0125$ was considered significant; for the target points (T1-T20), the critical α level was set to $P<.0029$. To determine a possible association between the

Figure 4. Measurements on human cadaver pelvis.

deviation of each reference point and its distance to the reference plate, we computed the Spearman rank correlation coefficient. The intraclass correlation coefficient (ICC) 2-way mixed model on absolute agreement was used to analyze measurement reliability between the 2 observers. In the interpretation of ICC coefficients, values of 0.75 or higher are indicative of excellent agreement beyond chance.

Results

In the comparison of the CT scan and measurements on the cadaver, 14 of 17 target points showed a mean deviation that was significantly lower with the MRO mounted on the ipsilateral ASIS than on the contralateral ASIS. Mean ipsilateral deviation (80 trials) was 1.1 mm, and mean contralateral deviation (80 trials) was 2.5 mm (P<.001).

The lowest mean deviation with the reference plate ipsilateral to the target points was 0.7 mm, and the highest was 2.25 mm. Mean contralateral deviation ranged from 0.93 mm to 3.53 mm. Ipsilateral measurements also revealed better values in variance. The 95% confidence intervals were 1.04-1.25 mm ipsilateral and 2.3-2.7 mm contralateral (Figure 5).

Testing of homogeneity of variance (Levene test) revealed significant differences in variance between ipsilateral and contralateral measurements for 16 of the 17 target points, whereas the ipsilateral measurements showed significantly better values (P<.001). The target points closer to the reference plate showed a lower mean deviation than the points farther from the plate. The correlation between the distance from the target points to the MRO and the deviation of the target points was highly significant (P<.001; r_s, 0.750) (Figure 6). There was no significant difference between ipsilateral and contralateral measurements of the reference points and the mean deviation of the 4 reference points. Mean deviation of the ipsilateral and contralateral reference points was 0.5.

The 2 raters' agreement as to the mean deviation of each target point to its reference plate was good (ICC, 0.747; P<.001).

Discussion

The accuracy of surgical approaches to the pelvis can be improved with CAS. We used an image-guided navigation

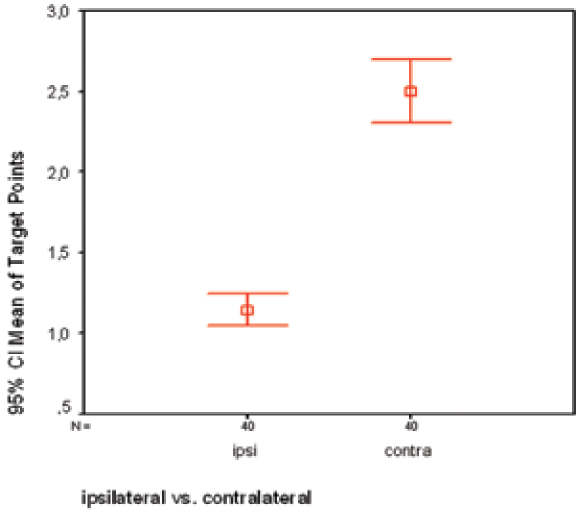

Figure 5. Deviation of target points from computed tomography measurements with regard to ipsilateral versus contralateral measurements.

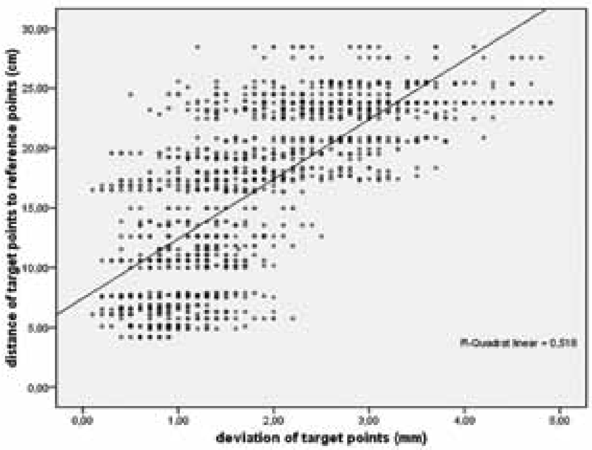

Figure 6. Correlation of deviations of all target points from computed tomography measurement with its distance to reference plate (P<.001; r_s, 0.750).

system combined with navigation software. Using the navigation system, a surgeon can approach every target point in the coronal, axial, and sagittal planes simultaneously. A 3-dimensional reconstruction of the pelvis is generated by the software to assist the surgeon with orientation.

We investigated the accuracy of an image-guided navigation system based on a new MRO. Registration is performed externally, and the patient lies in the supine, nonfixated position on the operating table. The surgical approach to the ASIS for the insertion of the navigation pin for the MRO is simple. It causes little soft-tissue damage and no muscle damage. The structure most at risk is the subcutaneous lateral femoral nerve, which is located distal to the ASIS. Longitudinal perforation may occur in some cases, and internal organs in the pelvis might be injured.

Soft-tissue variance does not affect the registration protocol, and neither do the dysplastic changes in the landmark surface. Previous studies[2] have found that bony landmarks (eg, frontal pelvic plane) are inaccurate for navigation procedures. Irrespective of the patient's body mass index, all bony landmarks are covered with tissue (mean coverage of pubic symphysis, 16.1 mm; mean coverage of ASIS, 7.1 mm). Therefore, bony landmarks that represent the anterior pelvic plane are less reclined than the plane defined by surface landmarks (mean necessary correction angle, 4.4°; range, 1.3°-5.5°). Previous studies also showed that mean deviation increases as the distance to the reference object increases.[4,5] Our study indicated the same pattern.

Our results indicated that the mean deviation with the MRO placed on the same half of the pelvis as the target screws was 1.1 mm, a value notably better than the values reported by other investigators.[4] In one study, Van Hellemondt and colleagues[4] used bony landmarks instead of an MRO, used a similar navigation system and software, and reported a mean deviation of 3.81 mm using a hemipelvic matching protocol with reference points of one ASIS, ipsilateral anterior inferior iliac spine (AIIS), and pubic symphysis. They also compared a hemipelvic matching protocol with a total pelvic protocol using reference points ipsilateral ASIS, ipsilateral AIIS, and contralateral ASIS. The total pelvic matching protocol showed a mean deviation of 4.86 mm. Therefore, our MRO appears to offer more effective registration than does the method of using bony landmarks.

Our study has its limitations. First, it was a cadaver study, and further clinical studies are needed to test the practicability of the MRO. Second, the sample size was small (n = 1 human cadaver pelvis). Third, although interobserver reliability was good (ICC, 0.747; $P<.001$), only 2 observers were involved in the sequence of measurements.

One disadvantage of CAS in pelvic surgery is that more time is needed for preoperative planning and intraoperative procedures. However, our experience has been that this time does not exceed 10 minutes before surgery and 5 minutes during surgery. In addition, intraoperative radiation exposure is reduced. Advantages of the MRO are that the patient can lie in either a supine or lateral position, and the method can be used in any region of the human body.

We believe that registration with this MRO during CAS is a safe and reliable registration method. However, further clinical studies are needed to test the practicability of this MRO.

Authors' Disclosure Statement

The authors report no actual or potential conflict of interest in relation to this article.

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