X-Ray Image-Guided Navigation for Hip Osteotomy

Computer Integrated Surgery II

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ABSTRACT & SIGNIFICANCE

Periacetabular osteotomy (PAO) is a joint reconstruction surgery intended to increase femoral head coverage and thereby improve stability in patients diagnosed with developmental dysplasia of the hip (DDH)[4]. The aim of this project was to develop a workflow and software pipeline for a novel, X-ray image-guided navigation system for performing PAO. The proposed method involves placing several metallic, radiopaque BBs on (1) the uncut pelvis ilium to provide a virtual reference frame, and (2) the bone fragment undergoing realignment to allowing fragment tracking. The fiducial registration errors and fragment transformation errors for the proposed method are compared to those obtained by the current, optical tracker-based navigation method.

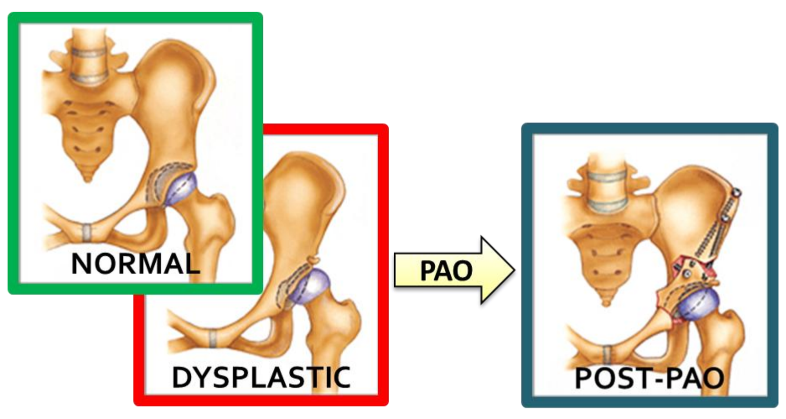


Fig. 1. Dysplastic hips may be repaired by periacetabular osteotomy (PAO).
http://www.hipandpelvis.com/patient_education/periace/page2.html

PROBLEM STATEMENT

The proposed method must above all be able to accurately compute the rigid transformation mapping the acetabular fragment from its preoperative position to its post-realignment position. Poses of X-ray images taken before and after the realignment must be estimated in order to obtain this transformation. The accompanying transformation errors must be compared to a ground truth value, which (in this case) was considered to be the fragment transformation as determined by the optical tracker-based navigation method.

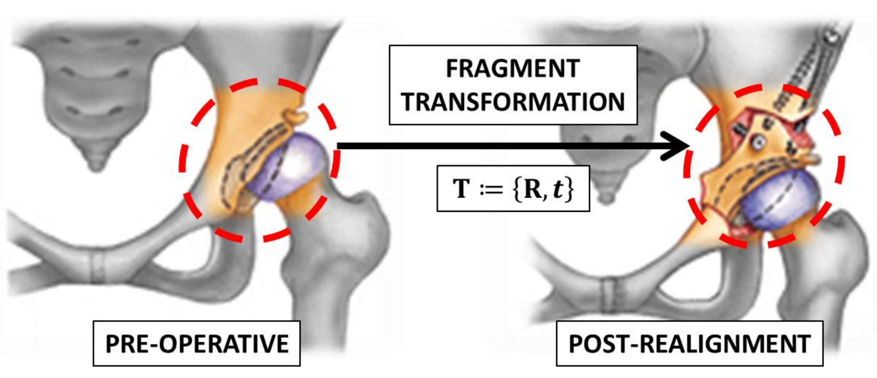


Fig. 2. The motion of the acetabular fragment can be described by a rotation and translation in the FTRAC, optical tracker rigid body, and local reference frames.
http://www.hipandpelvis.com/patient_education/periace/page2.html

METHODOLOGY

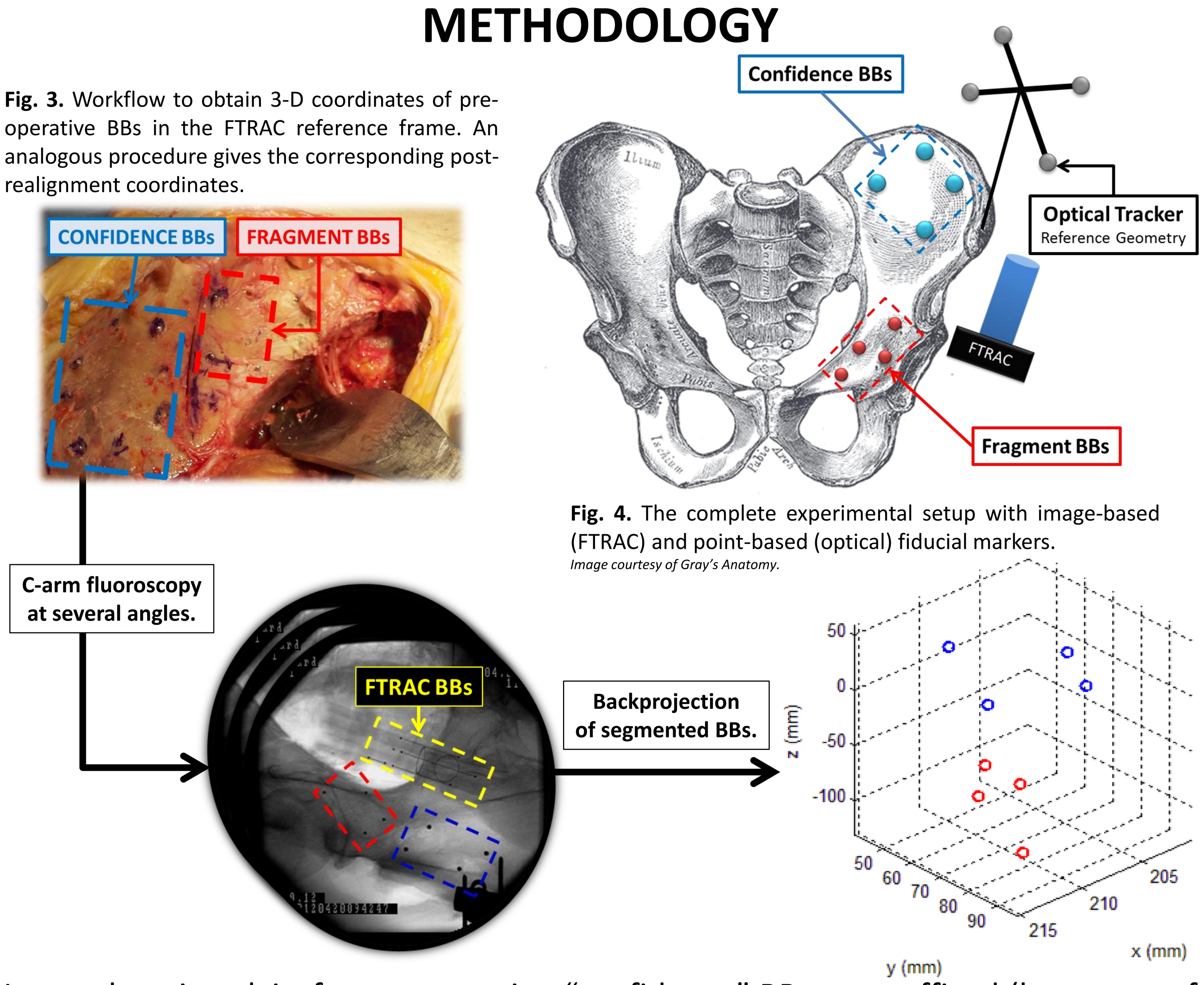
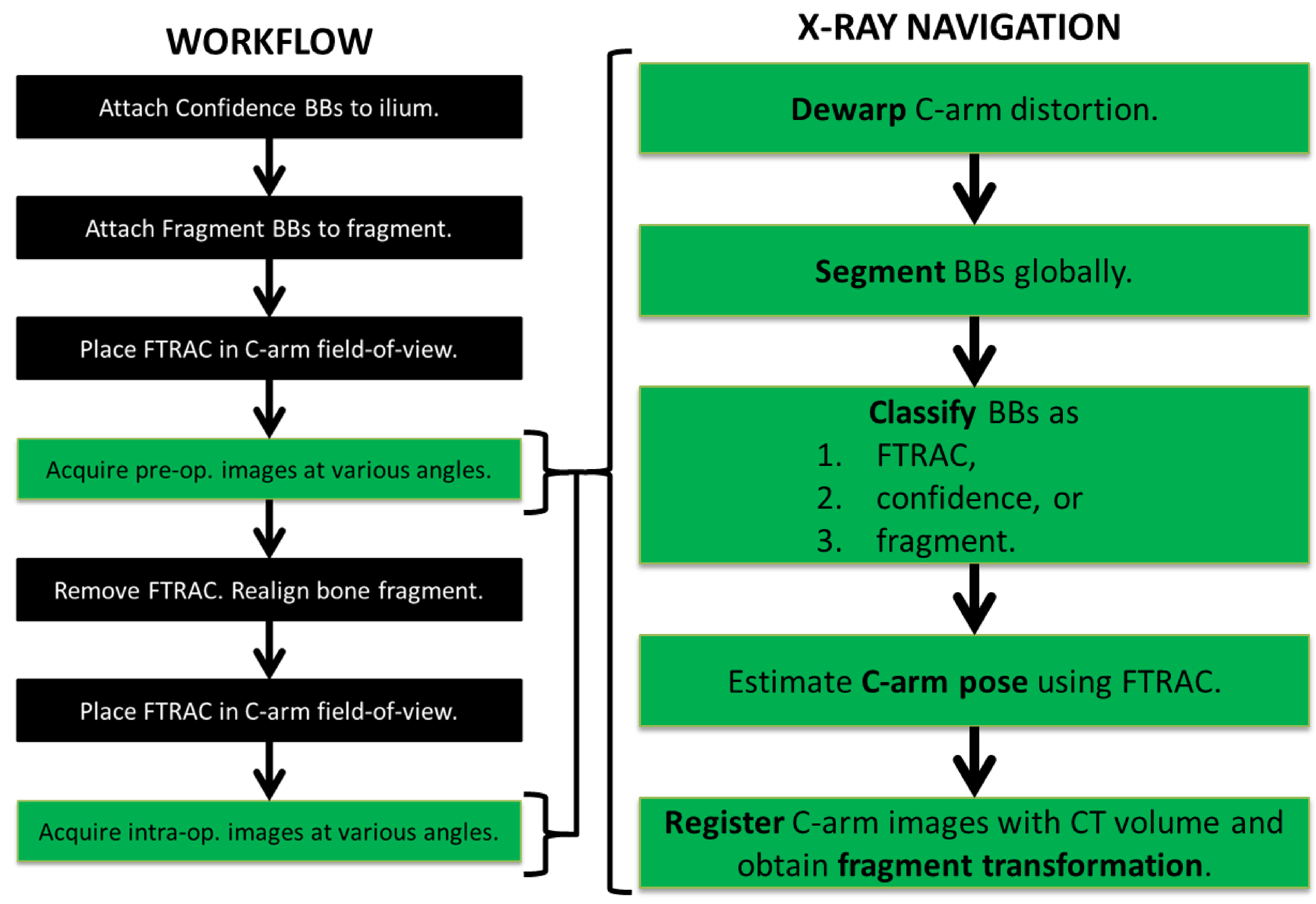


Fig. 3. Workflow to obtain 3-D coordinates of pre-operative BBs in the FTRAC reference frame. An analogous procedure gives the corresponding post-realignment coordinates.

Fig. 4. The complete experimental setup with image-based (FTRAC) and point-based (optical) fiducial markers.
Image courtesy of Gray's Anatomy.

In a cadaveric pelvis, four non-moving "confidence" BBs were affixed (by means of drilling and glue) to the subject's ilium to provide a virtual reference frame. Then, four "fragment" BBs were affixed to the acetabular fragment cut by the surgeon. At that time, a number of "pre-op" X-ray images of the surgical site were acquired at several angles using a C-arm imager. The fragment was subsequently reoriented by the surgeon during the PAO procedure. Upon reorientation, several "intra-op" X-ray images were acquired in a similar fashion. During both acquisition periods, a fluoroscopic tracker (FTRAC[2]) was non-rigidly placed in the field-of-view to permit pose recovery and computation of the rigid transformation undergone by the fragment with respect to the FTRAC reference frame. Concurrently, optical tracker-based navigation was used to obtain an analogous transformation in the optical tracker reference frame which was treated as the ground truth in error analyses.

PROPOSED PIPELINE



RESULTS & DISCUSSION

Fiducial registration errors (FRE) between the optical and x-ray navigated systems were compared using four sets of points and the two pose estimation algorithms, Expectation Conditional Maximization (ECM[3,5]) and Pose from Orthography with Scaling (POSIT[1]). FRE was computed by applying a point cloud registration to transform points from x-ray image space to optical tracker space to get estimated optical points, then calculating the mean distance between measured and estimated optical points.

Table 1. Fiducial registration error (mm)

	ECM		POSIT	
Realignment	*Confidence*	*Fragment*	*Confidence*	*Fragment*
Pre	3.28	3.57	3.12	3.75
Post	2.61	3.98	1.72	4.40

Transformations between confidence and fragment points in pre- and post-realignment positions were compared between the optical- and X-ray-navigated methods. The table below shows rotational and translational errors in the error transformation, defined as $T^{err} = (T^{Xray})^{-1} \cdot T^{Opt}$. The two figures below show the coordinate frames used in the error analysis (FRF = fragment reference frame,

Pose Estimation Algorithm	translational error (mm) x	y	z	rotational error (deg) θx	θy	θz
ECM	4.77	-4.03	-12.27	9.27	9.27	3.93
POSIT	2.65	0.03	-12.90	8.86	8.99	4.67

Table 2. Error in pre-to-post fragment transformation

The translational error is largest in the z-direction, perpendicular to the imaging plane. In general, POSIT yields slightly smaller errors in FRE and transformation error. Error may have been introduced by manual segmentation of BB positions in the x-ray images and the large diameter of confidence BBs.

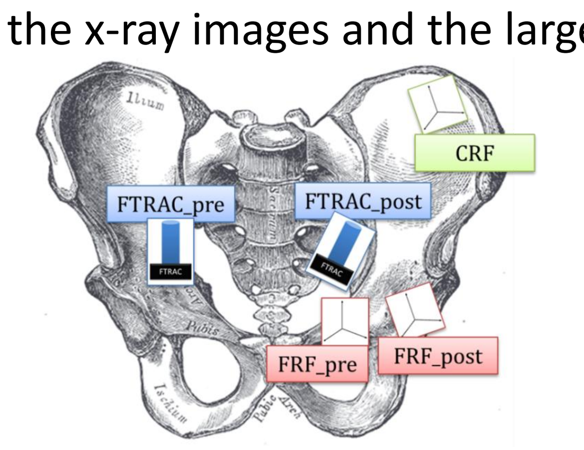


Fig. 5. X-ray navigation coordinate frames.

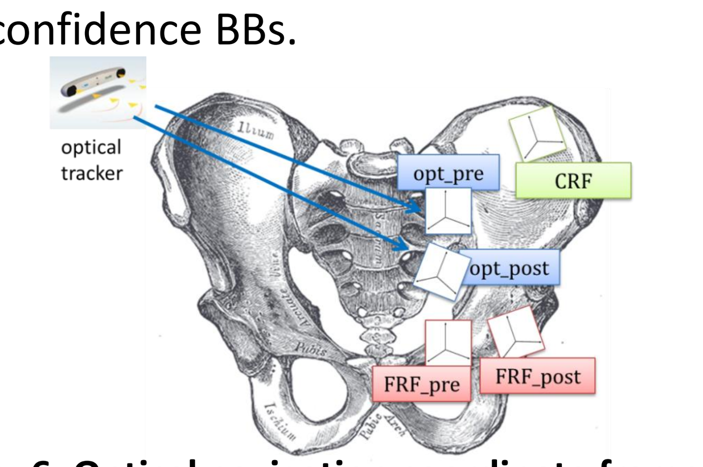


Fig. 6. Optical navigation coordinate frames.

REMAINING WORK & LESSONS LEARNED

A reasonable continuation of this work would begin with an in-depth analysis of the errors produced by the proposed method. Next, the authors recommend integration of the proposed method with the existing BGS software and a cadaver study to test its online function. Also, the determination of BB correspondences should be fully automated via epipolar geometry techniques. Working in multiple coordinate systems was not a simple matter, but it proved to be a useful, intuition-developing exercise. Also, designing and executing a cadaveric study presented particularly interesting challenges.

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