X-Ray Image-Guided Navigation for Hip Osteotomy

Computer Integrated Surgery II
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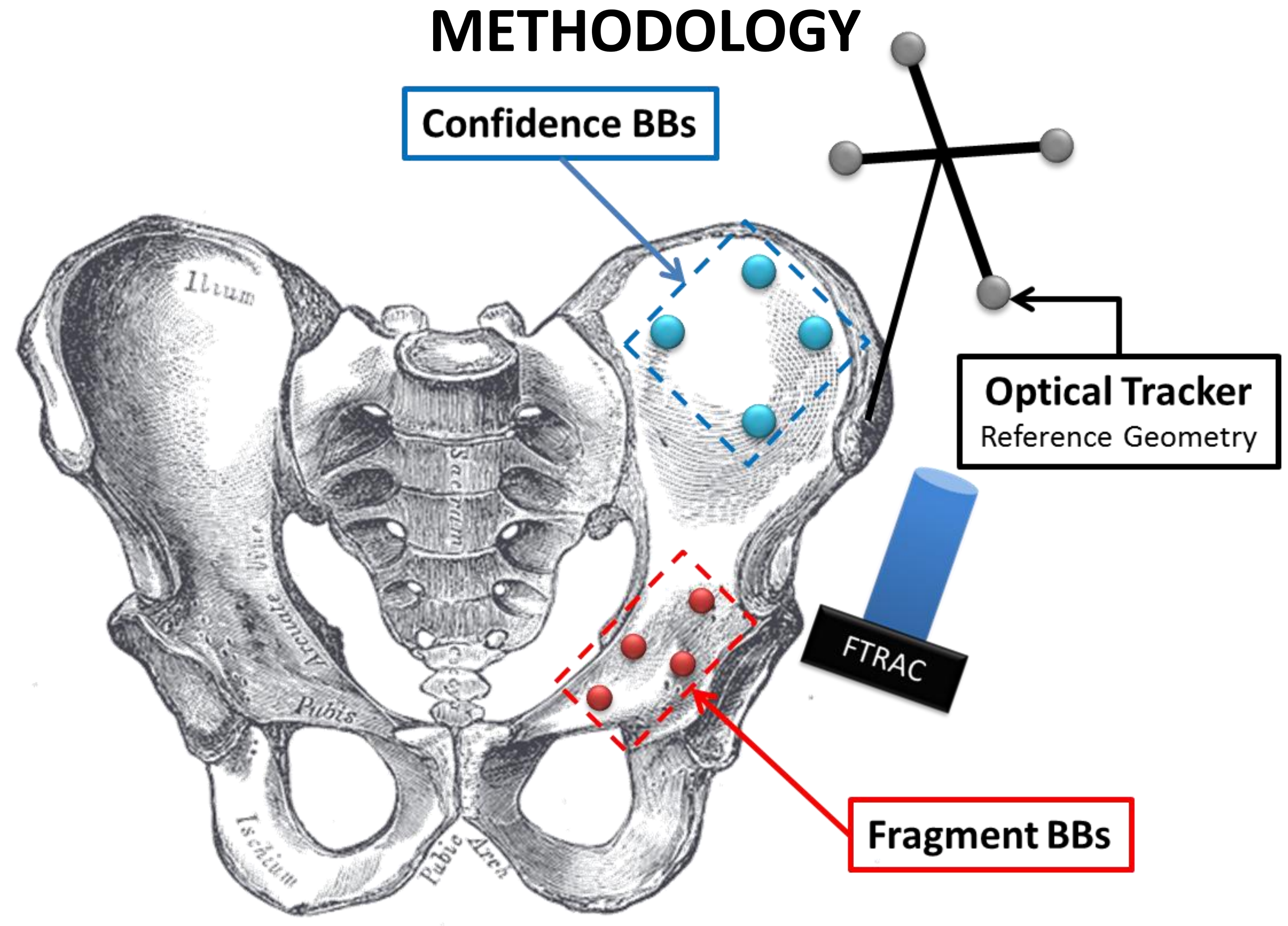
SUMMARY

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). The first 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 second aim was to compare the proposed pipeline to the current optical tracker-based navigation procedure. 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 error in the fragment transformation is considered in the results.

PROBLEM STATEMENT

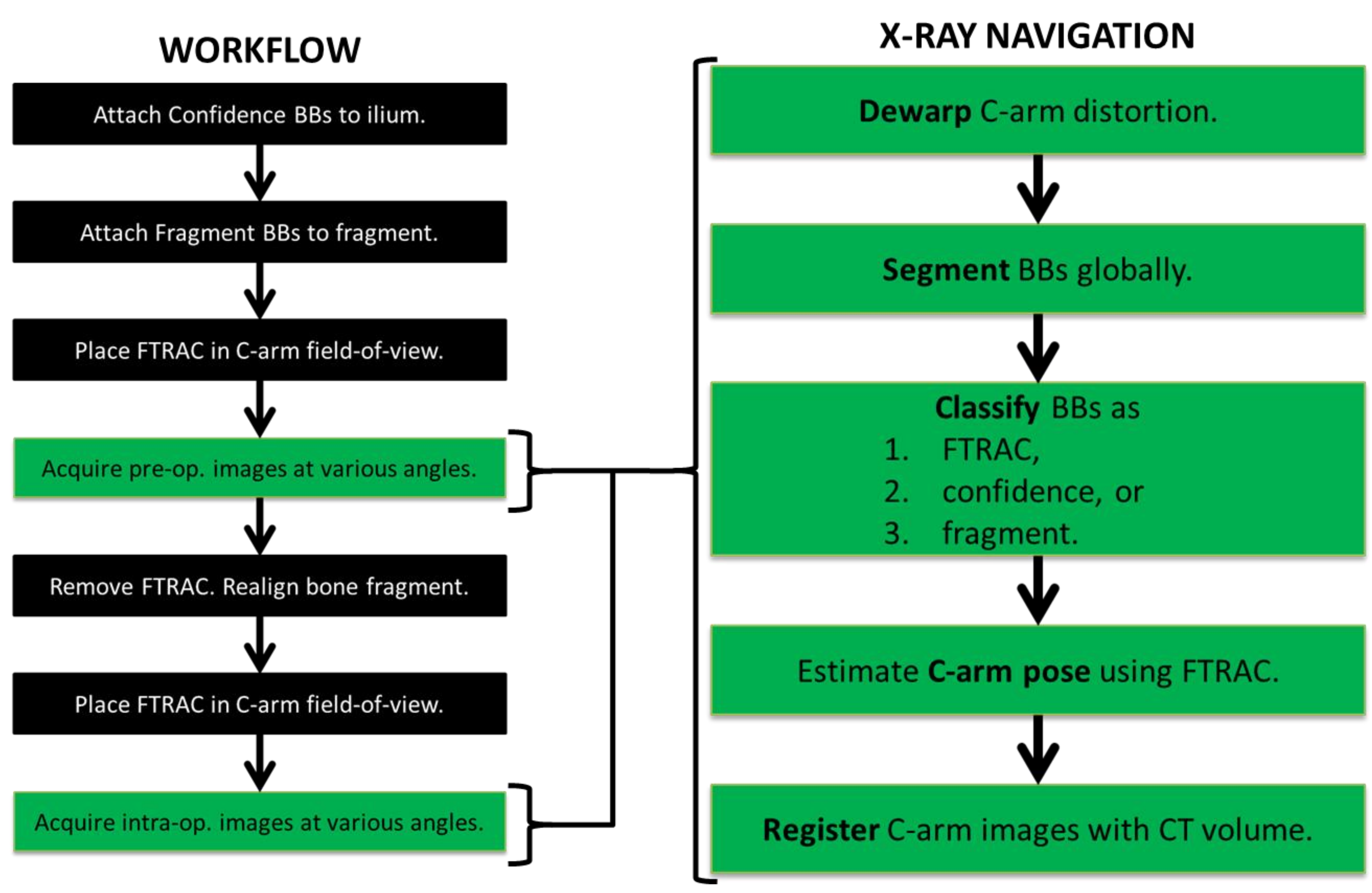
The proposed method must accurately compute the rigid transformation mapping the acetabular fragment from its preoperative position to its post-realignment position. Poses of X-ray images taken before and after the realignment must be estimated in order to obtain this transformation. The accompanying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

METHODOLOGY



In a phantom pelvis and 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) was non-rigidly placed in the field-of-view to permit pose recovery and computation of the rigid transformation undergone by the fragment. Concurrently, optical tracker-based navigation was used to obtain a registration, and it was treated as the ground truth in error analyses.

SURGICAL PIPELINE



RESULTS & DISCUSSION

The reliability of optical and X-ray measurements was verified by computing the fiducial registration error (FRE) between both methods on four sets of points. Two pose estimation algorithms were also tested: expectation conditional maximization (ECM) and pose estimation with orthography and scaling (POSIT).

FRE (mm) between optical and x-ray methods

	ECM		POSIT	
	confidence	fragment	confidence	fragment
pre-reorientation	24.4857	39.4066	23.409	11.1359
post-reorientation	12.4944	36.7075	37.1234	38.3994

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 (deg) and translational errors (mm) in the error transformation, defined as $T^{err} = (T^{Xray})^{-1} \cdot T^{Opt}$.

Translational and rotational errors in T^{err} for the transformation ${}^{fragPre}T_{fragPost}$

Pose Estimation	X	Y	Z	θ_x	θ_y	θ_z
ECM	13.7408	-9.9761	1.8035	2.7315	6.2377	1.9952
POSIT	9.5592	-7.5497	0.1462	2.0437	7.0691	4.7816

FUTURE WORK

A proper continuation of this work would consist of an 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 automated via epipolar geometry.

LESSONS LEARNED

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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