Recovery of 3D component position in reverse shoulder arthroplasty from postoperative radiographs via 2D/3D registration

Michael Hachadorian MD[1], Vivek Gopalakrishnan BS[2,3], Jason Hsu MD[1]

1. Department of Orthopaedics and Sports Medicine, University of Washington, Seattle, WA, USA
2. Harvard-MIT Health Sciences and Technology, Cambridge, MA, USA
3. MIT Computer Science and Artificial Intelligence Laboratory, Cambridge, MA, USA

Introduction:
Reverse shoulder arthroplasty (RSA) is increasingly popular due to implant advancements, expanding indications, and a growing active aging population. Unlike anatomical reconstruction, RSA intentionally alters native anatomy, but the full implications of these changes remain highly debated. Postoperative glenosphere assessment is crucial to understanding its effects on muscle lengths and force production, stresses on the acromion, impingement-free range of motion, and glenoid component loosening. While preoperative planning focuses on optimizing component positioning, accurate postoperative assessment is limited by the projectional nature of X-rays, making precise 3D evaluations from 2D imaging impossible. CT scans provide more accurate measurements but are impractical for routine use due to cost, radiation exposure, and metal artifacts. However, recent advances in computer graphics and optimization have enabled accurate registration of anatomical structures in postoperative 2D radiographs to preoperative 3D CT scans. This study develops a novel method to measure glenosphere positioning in 3D space from postoperative radiographs following RSA via differentiable 2D/3D registration.

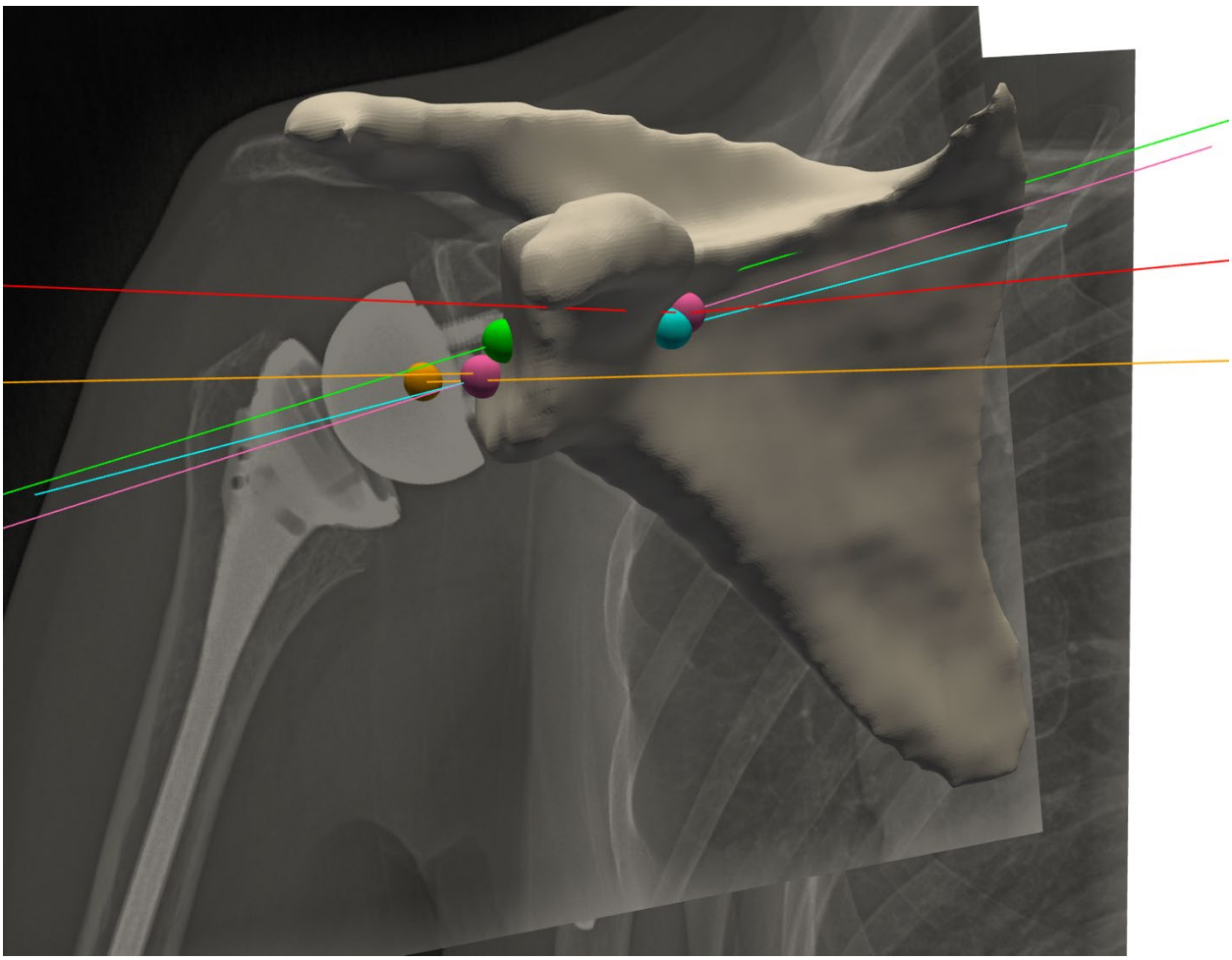
Methods:
Patients from a shoulder arthroplasty database were screened for inclusion. Those with both preoperative and postoperative CT scans as well as postoperative radiographs were selected. 3D volumetric reconstructions were generated from the preoperative and postoperative CT scans. Fiducial landmarks were placed manually to define the scapular axis in the preoperative CT scan, and to define the glenosphere center of rotation and the tip of the central baseplate screw in postoperative radiographs and CT scan. A differentiable X-ray renderer was used for semi-supervised 2D/3D image registration, aligning the position of the scapula in postoperative radiographs to the preoperative CT scan. The scapular pose in the postoperative radiograph was estimated using iterative optimization, maximizing similarity of the scapula rendered from the CT to the real radiograph through gradient-based optimization. Once successfully registered, the axis of the central screw and position of the glenosphere in 3D were determined by back projecting the 3D fiducial landmarks. These estimates were compared against the postoperative CT scan to quantify differences in implant position derived from each measure.

Results:
The imaging from five patients was evaluated. The mean difference between the XR and CT based central screw to scapular axis angle was 2.5º (IQR 1.0º - 3.8º).

Discussion/Conclusion:

This study demonstrates that measures of glenosphere position and orientation using novel 2D/3D registration application are accurate and precise when compared to postoperative CT of the same patient. This method minimizes the differences in measurement that are attributable to variation in XR beam angle. Utilization of this technology has the potential to benefit surgeons in better understanding the final positioning of the glenosphere in the context of the patient's preoperative anatomy. Future studies directed at retrospectively assessing glenosphere positioning as well as changes from baseline give may present ability to describe changes intraoperatively in a more universal language.

1A:



1B:

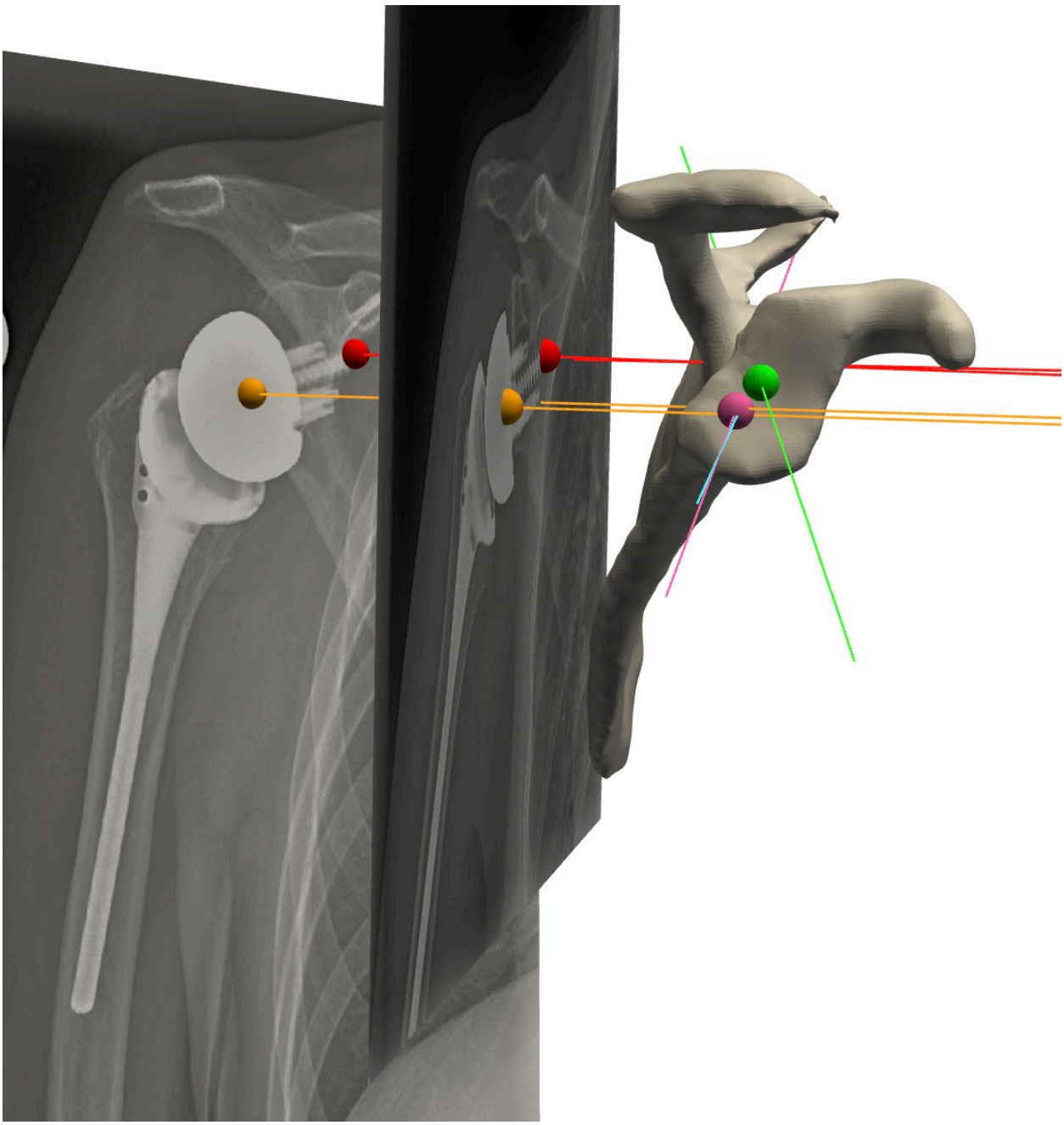


Figure 1:

Reconstructed visualization of a single patient's shoulder. The 3D reconstructed volume from pre-operative CT is overlaying the patient's postoperative radiographs. Radiographic landmarks for glenosphere COR (orange) and central screw tip (red) and the resulting composite 3D central screw axis (pink). Central screw axis based off postoperative CT (blue). Scapular axis defined by trigonum spinae to glenoid center point (green). A) Anterior viewing point. B) Lateral viewing point.