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ORIGINAL ARTICLE

Sequential 3-dimensional computed tomography analysis of implant position following total shoulder arthroplasty

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Background: Detection of postoperative component position and implant shift following total shoulder arthroplasty (TSA) can be challenging using routine imaging. The purpose of this study was to evaluate glenoid component position over time using 3-dimensional computed tomography (CT) analysis with minimum 2-year follow-up.
Methods: Twenty patients underwent primary TSA with sequential CT scanning of the shoulder: a preoperative study, an immediate postoperative study within 2 weeks of surgery, and a postoperative study performed at minimum 2-year follow-up (CT3). Postoperative glenoid component position and central peg osteolysis were assessed across the immediate postoperative CT scan and CT3. Glenoids with evidence of component shift and/or grade 1 central peg osteolysis on CT3 were considered at risk of loosening.
Results: Of the patients, 7 (35%) showed evidence of glenoid components at risk of loosening on CT3, 6 with component shift (3 with increased inclination alone, 1 with increased retroversion alone, and 2 with both increased inclination and retroversion). Significantly more patients with glenoid component shift had grade 1 central peg osteolysis on CT3 compared with those without shift (83% vs 7%, $P = .002$). One clinical failure occurred, with the patient undergoing revision to reverse TSA for rotator cuff deficiency.
Conclusions: Three-dimensional CT imaging analysis following TSA identified changes in glenoid component position over time, with inclination being the most common direction of shift and grade 1 central peg osteolysis commonly associated with shift. These findings raise concern for glenoids at risk of loosening, but further follow-up is needed to determine the long-term clinical impact of these findings.
Level of evidence: Level II; Prospective Cohort Design; Treatment Study

Keywords: Total shoulder arthroplasty; glenoid component; computed tomography; three-dimensional analysis; component shift; component osteolysis; component loosening

Institutional review board approval was obtained for this study (Cleveland Clinic IRB study No. 12-1098).

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Glenoid component loosening is the most common complication following total shoulder arthroplasty (TSA).[2,12] However, the causes of loosening and their impact on implant longevity are not well defined. Implant design and fixation have been shown to play a significant role,[38,39] while

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component position also is critical to long-term prosthetic survival and clinical success.[4,17,19,21,25,32,33,48,57,59] Persistent glenoid retroversion and posterior subluxation of the humeral head, in particular, have been shown to be associated with an increased rate of glenoid component loosening, likely because of the eccentric location of the humeral head in relation to the center of the glenoid component.[11,15,17,19,25,32,33,48-50,53,57,58,59] While surgical techniques and component placement can correct preoperative pathology to center the humeral head within the glenoid, the factors associated with both correction and maintenance of this relationship over time have not been well defined.

Radiographic imaging can be used for postoperative assessment of component position following TSA; however, this has been hampered by difficulties with standardization and reproducibility of sequential postoperative radiographs, limiting their sensitivity to change and the accuracy of measurement.[18,26,60] Computed tomography (CT) can provide more accurate measurement of glenoid and humeral head anatomy preoperatively,[6,23,24,43] but postoperative analysis to quantify glenoid component position and radiolucencies using standard CT may still have limitations due to difficulty in precisely identifying a polyethylene component and due to metal artifact from the implant.[1,27,30,60] New techniques in the acquisition, reconstruction, and post-processing of CT images now available for clinical use and optimization of patient positioning, however, have been shown to be able to significantly reduce metal artifact.[14,28,29,31,34,51,52,55,56] In addition, 2-dimensional and 3-dimensional (3D) analysis appears to significantly affect measurements made on CT, such as glenoid version.[3,5-7,60] Three-dimensional analysis techniques appropriately aligned with the plane of the scapula may be more reliable and accurate.

We have developed and validated methods for postoperative 3D CT imaging analysis of the shoulder that allow for precise determination of implant position of a polyethylene component, with the potential to detect more subtle changes in component position or loosening over time.[22] Accurate evaluation of component position and change in position over time can lead to a better understanding of implant longevity and clinical success. While standard imaging may be able to qualitatively detect gross implant failure, potentially more important is the ability to quantitatively identify more subtle component shift that is not detectable with routine imaging techniques. Although such movement may be clinically silent in the short term, its presence may be predictive of premature clinical failure, as has been reported with radiostereometric analysis (RSA).[37,39,44] RSA is an established, highly accurate method of detecting subtle component migration over time following TSA[38,39,41]; however, its use has been limited because of the need for specialized imaging equipment and analysis that limits its widespread clinical application. In contrast, CT is widely available and, when used in combination with new metal artifact reduction techniques and 3D CT imaging analysis, has the potential to address the limitations of plain radiographs and RSA.

Therefore, the purpose of this study was to evaluate glenoid component position over time using sequential 3D CT imaging analysis with minimum 2-year follow-up to better define preoperative and postoperative anatomic and implant factors that contribute to glenoid component shift over time.

Materials and methods

At a mean follow-up of 33 ± 3 months (range, 27-40 months), 20 patients (8 men and 12 women) who underwent primary TSA with a polyethylene anchor peg glenoid component for advanced glenohumeral arthritis were evaluated with routine plain radiographs and the Penn Shoulder Score. The mean age at the time of surgery was 68 ± 8 years (range, 53-86 years). Fourteen patients had placement of a standard anchor peg glenoid component (Global Anchor Peg Glenoid; DePuy Synthes, Warsaw, IN, USA) and 6 had placement of a posteriorly augmented glenoid component (Global STEPTECH Anchor Peg Glenoid; DePuy Synthes) to address glenoid bone loss. All patients prospectively underwent sequential CT scanning of the shoulder: a preoperative study (CT1), an immediate postoperative study within 2 weeks of surgery (CT2), and a postoperative study performed at latest follow-up (CT3). All but 1 patient was previously a part of an institutional review board–approved randomized controlled clinical trial to evaluate the effect of patient-specific instrumentation on implant placement in TSA and had undergone CT2 as a part of the prior study.[16]

Preoperative and postoperative CT scans of the operative shoulder were performed on CT scanners (SOMATOM Sensation 64, Definition DS, Definition AS+, Definition EDGE, or Definition FLASH; Siemens Healthcare, Erlangen, Germany) using a single energy protocol with 140 kV (peak), 300 quality reference mA with CARE Dose4D (tube current modulation; Siemens Healthcare), and 0.6-mm collimation. Preoperative scans were reconstructed using a standard filtered backprojection algorithm and postoperative scans were reconstructed using an enhanced metal artifact reduction algorithm (iterative metal artifact reduction [iMAR]; Siemens Healthcare) in the axial plane with a medium-smooth kernel (B40) and 0.6-mm slice thickness.[34,52] Patients were scanned in the supine position with the operative arm at the side of the body. DICOM (Digital Imaging and Communications in Medicine) images from the preoperative and postoperative CT scans were then imported into custom-designed 3D imaging software (Arthroplan; Cleveland Clinic, Cleveland, OH, USA) for further analysis, as previously described and detailed later.[8,10,16,18,22,24,42,45-47,61] The software allows for reconstruction and viewing of bony structures and TSA components in 3D and simultaneously in 3 orthogonal planes (axial, coronal, and sagittal) referenced to the scapular plane. It includes measurement tools and 3D digital component templating that allow for the determination of component position.

Measurements on preoperative and postoperative CT scans

Preoperative CT scans were used to measure glenoid and humeral head anatomy, as previously described.[8,10,16,18,22,24,42,45-47,61] Glenoid version, inclination, and joint line were measured in 3D and referenced to the plane of the scapula (Fig. 1). Best-fit sphere placement to the native humeral head was performed using a validated method to define the center of the humeral head for measurement of humeral