Prediction of Scapular Notching using 3D CT Simulation Software and Video-Based Motion Analysis

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Disclosures:  J. Kolmodin: None. I. Davidson: None. B. Jun: None. N. Sodhi: None. N. Subhas: 5; Siemens Healthcare Solutions, INC. T.E. Patteson: None. Z. Li: None. J.P. Iannotti: 1; Biomet, DePuy, Synthes, Integra, Musculoskeletal Transplant Foundation, Tornier, Zimmer. 2; DePuy, Synthes, Zimmer. 3B; DePuy, Synthes, Tornier. 7; Wolters Kluwer Health - Lippincott Williams & Wilkins. E.T. Ricchetti: 5; DePuy, Tornier.

Introduction: Scapular notching is frequently observed following reverse total shoulder arthroplasty (rTSA) \(^1\). Many clinical and computer simulation studies have sought to identify its associated factors \(^2\-^5\). However, the rate of scapular notching remains substantial, suggesting that scapular notching is not well understood. The lack of understanding may result from the limitations of clinical studies or computer simulations. We have therefore developed new clinical imaging that defines patient specific factors within a computer simulation model that can define patient specific association with observed scapular notching. We hypothesized that scapular notching would be dependent upon patient specific implant placement, pre-operative scapula anatomy and the post-operative range of motion. We hypothesized that the observed post-operative periprosthetic bone loss seen on 3D post-operative CT imaging would correlate with patient specific implant position, pre-operative bony anatomy, and humeral motion measured by video-based motion analysis (VMA) \(^6\).

Methods: Fourteen patients with pre-operative CT scans that underwent a Grammont type rTSA were re-evaluated at a minimum of two years from surgery (mean follow up 44.3 months ± 14.6 months) with VMA, 3D post-operative CT scanning with metal artifact reduction techniques, standard radiographs and physical examination. Active glenohumeral and scapulothoracic range-of-motion was measured in 3D using VMA. The pre-operative and post-operative scapula were registered within a 3D simulation software so that the position of the implants determined on the post-operative CT scan allowed placement of the virtual implant on the pre-operative scapula. The glenohumeral motion obtained from that patient’s VMA was then placed within the 3D simulator and humeral implant contact on the scapula bone (impingement) was compared with impingement-free ROM that was determined in the simulator. When the patient’s actual range of motion exceeded the impingement-free range of motion we would expect to see notching on the post-operative imaging in the specified location (figure 1). Additionally, we evaluated the type and amount of glenosphere position that would avoid impingement assuming the same range of motion in that patient.

Results: There was radiographic evidence of scapular notching in 9 of the 14 patients studied. When simulating patient-specific ROM within our software, impingement was observed (and scapular notching would have been predicted) in all 9 patients. In the remaining five patients studied there was no radiographic evidence of scapular notching, and impingement was not observed when simulating patient-specific ROM. Impingement was found to occur with neutral humeral adduction in 6 patients,
with humeral external rotation in 9 patients, and with humeral internal rotation in 3 patients. For 8 of the 9 patients with impingement, placing the implant in a more inferior position (average of 1.8mm) or a more lateral position (average of 2.6 mm) would have avoided impingement. In only one case was a combination of both inferior and lateral position necessary to avoid impingement. When using a reverse implant having a medial center of rotation, inferior placement of the glenosphere in relation to the inferior part of the glenoid bone was the most significant factor associated with impingement and notching (5.58 mm vs. 2.38 mm, p=0.005).

**Discussion:** Simulation of bony impingement using 3D CT simulation software and VMA is predictive of the presence and location of scapular notching. Patient specific active range of motion is an important factor in the occurrence of notching and is a factor not considered in previously performed clinical or simulation studies. Our results demonstrate inferior scapular notching due to bony impingement occurs with both adduction of the arm as well as with rotational motions - specifically humeral external rotation with the arm in 10-20 degrees of abduction. Inferior and/or lateral placement of the glenosphere is an important factor in avoiding notching, particularly when using a design having a medial center of rotation.

**Significance:** Despite recent advances in implant positioning and surgical techniques, scapular notching remains a common radiographic finding following rTSA. Our results demonstrate that only small changes in implant position are needed to avoid impingement, suggesting that pre-operative determination of ideal implant position may be helpful to avoid notching post-operatively. Patient-specific bony anatomy and post-operative range of motion are also factors that determine scapular notching.

Figure 1. Patient-specific range of motion (gray) and implant impingement-free range of motion (black).

ORS 2015 Annual Meeting

**Paper No:** 0172