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Three-dimensional in vivo kinematics of an osteoarthritic shoulder before and after total shoulder arthroplasty

Jonathan P. Braman,
Department of Orthopaedic Surgery, University of Minnesota, 2450 Riverside Avenue, R200, Minneapolis, MN 55454, USA

Brian M. Thomas,
Department of Orthopaedic Surgery, University of Minnesota, 2450 Riverside Avenue, R200, Minneapolis, MN 55454, USA

Robert F. LaPrade,
Department of Orthopaedic Surgery, University of Minnesota, 2450 Riverside Avenue, R200, Minneapolis, MN 55454, USA

Vandana Phadke, and
Department of Physical Medicine and Rehabilitation, University of Minnesota, 420 Delaware St SE, MMC 388, Minneapolis, MN 55455, USA

Paula M. Ludewig
Department of Physical Medicine and Rehabilitation, University of Minnesota, 420 Delaware St SE, MMC 388, Minneapolis, MN 55455, USA

Jonathan P. Braman: brama011@umn.edu

Abstract

A case of a patient with glenohumeral joint arthritis is presented which demonstrated the three-dimensional shoulder motion before and after total shoulder arthroplasty. Pre-operative shoulder motion differed compared to normal controls, while post-operatively her glenohumeral-to-scapulothoracic motion ratios were restored to near normal ratios.

Keywords

Glenohumeral joint; Scapula; Biomechanics

Introduction

Glenohumeral osteoarthritis is a relatively uncommon, but debilitating, disease of the shoulder. Pain and restricted range of motion are typical symptoms. Progressive deterioration of articular cartilage within the glenohumeral joint results in changes in the shape and function of the glenohumeral articulation.

Primary treatment consists of activity modification and pain management. In patients with end-stage osteoarthritis, however, total shoulder arthroplasty is indicated. Excellent long-term functional outcomes have been reported in patients undergoing shoulder arthroplasty [2,12].

Correspondence to: Jonathan P. Braman, brama011@umn.edu.

No study to date, however, has documented the in vivo three-dimensional kinematics of an osteoarthritic shoulder preoperatively and following total shoulder arthroplasty.

In previous studies, various techniques including surface sensors and bone pins have been used to measure kinematics in healthy subjects and those with shoulder pathology [1,3,5,6,9–11]. Invasive pins provide better rigid fixation to the osteology and therefore, should improve the accuracy of shoulder motion analysis. However, the invasive nature of this technique has limited its use. This case report is from a series of patients analyzed for a larger study. This patient ultimately underwent total shoulder arthroplasty. Post-operative data were collected from surface sensors. Therefore, the three-dimensional clavicular, scapular and glenohumeral kinematics of an osteoarthritic shoulder in these planes, using direct bone-fixed tracking is described.

Materials and methods

A 59-year-old woman (1.63 m tall, 79.5 kg, BMI 29.9) participated in an Institutional Review Board-approved study that directly tested in vivo scapular and glenohumeral kinematics of subjects with and without shoulder pain using bone-fixed tracking [10]. Utilizing local anesthesia and sterile technique, stainless steel transcortical pins were inserted into her scapular spine, distal clavicle, and lateral humerus via a fluoroscopy-guided handheld drill. Motion sensors were rigidly fixed to the pins using an electromagnetic tracking system (Ascension Technology Co, Burlington, VT, USA), and a skin marker was attached to the sternum to record trunk position. The Flock of Birds system is accurate to 1.8 mm and 0.5 degrees. Kinematic data were collected for 2 repetitions each of open-chain shoulder forward flexion, abduction, and scapular plane abduction (40 degrees anterior to the coronal plane) without weight in the hand.

The subject's shoulder motions were described by calculating the scapulohumeral rhythm as well as graphing glenohumeral, scapular, and clavicular kinematics in various rotational planes when compared to average healthy subject data from previous work [1,10].

Approximately 3 months after the pin testing, the subject's pain continued and she presented for clinical treatment. On both the anterior and posterior views, a circumferential humeral head osteophyte was observed, and a smaller glenoid osteophyte was visible on the anterior view (Fig. 1a). Pre-operatively, clinical examination showed 130 degrees of forward elevation, 115 degrees of lateral elevation, external rotation at the side of 40 degrees, internal rotation at the side to the greater trochanter, 40 degrees of external rotation in abduction, and −15 degrees of internal rotation in abduction. She underwent total shoulder arthroplasty. Surgery was performed through a standard deltopectoral approach with a cemented pegged polyethylene glenoid and an uncemented humeral component (Zimmer, Warsaw, IN USA) (Fig. 1b).

Results

Pre-operatively, the subject had diminished scapulohumeral rhythm ratios compared to asymptomatic subjects tested in previous shoulder motion studies [1,6,10]. Her scapulohumeral rhythm ratios from 30°-to-maximum during abduction, flexion, and scapular plane abduction were calculated. For every 1 degree of glenohumeral elevation, she had upward scapular rotation of 1.9° in abduction, 0.7° in flexion, and 1.3° in scapular plane abduction. This compared to 0.4°, 0.4°, and 0.4° in healthy individuals. These values yielded scapular rhythm ratios of 0.5:1, 1.2:1, and 0.7:1 compared to healthy subject values of 2.1:1, 2.3:1, and 2.2:1. These values demonstrate excess scapular motion or scapular "substitution".

Moreover, humeral angular elevation ranges relative to the trunk were noticeably lower (100° abduction, 130° flexion and scapular plane abduction) compared to healthy subjects (Fig. 2).

Also, after 50° of humerothoracic elevation, the glenohumeral elevation had a lesser slope for flexion (Fig. 2). Finally, scapular upward rotation demonstrated a steeper slope than normal asymptomatic subjects beginning at 60° of humerothoracic elevation (Fig. 3). These data and graphs demonstrate increased scapular upward rotation. Increased scapular posterior tilting for this patient relative to averages for healthy subjects was also visually observed when graphing shoulder flexion (Fig. 4).

This excess scapular motion became more apparent when graphing acromioclavicular joint motions (Figs. 5, 6). Increases in upward rotation and posterior tilting occurred for scapular motion relative to the clavicle at the acromioclavicular joint when compared to average values for healthy subjects.

Upon returning to normal function at 5 months postoperatively, she had repeat clinical testing. In lieu of invasive pin re-testing, surface sensors were attached to her acromion, distal humerus, and sternum to test for three-dimensional motion changes (Fig. 7). Surface motion testing followed established protocols [8,13]. When re-tested, our subject's scapulohumeral rhythm markedly improved. Her scapulohumeral rhythm ratios from 30° -to-maximum increased for abduction (1.9:1), flexion (1.8:1), and scapular plane abduction (1.2:1). These glenohumeral-to-scapulothoracic ratios corresponded to the scapula rotating in an upward direction 0.5°, 0.5°, and 0.7° for every 1° of glenohumeral elevation. Unlike her pre-operative data, the post-operative curves for glenohumeral elevation and scapular upward rotation closely resembled healthy subject data (Figs. 2, 3). Furthermore, she demonstrated increases in humeral external rotation across all humeral elevation angles after undergoing total shoulder arthroplasty (Fig. 8).

Discussion

The most important finding in this study was that total shoulder replacement can restore normal ratios of scapulothoracic motion in an osteoarthritic patient. Additionally, baseline motion abnormalities in a patient with end-stage glenohumeral arthritis were described.

Pre-operatively, this subject had a diminished scapulo-humeral rhythm ratio. These values were comparable to the abnormal pre-operative ratio of 0.32:0.68 during scapular plane abduction previously reported in patients with glenohumeral osteoarthritis [4] and below the healthy subject range of 1.35:1–2:4 described in other studies [1,6,10]. In assessing pre-operative motion, all glenohumeral measurements were substantially lower than the asymptomatic subject data set [1,10]. This subject's pre-operative scapulothoracic motion exhibited increased upward rotation in order to compensate for loss of glenohumeral motion and still maintain overall elevation. These kinematic results are similar to a prior study that demonstrated greater scapular upward rotation and altered scapulohumeral rhythm [4]. With the additional availability of acromioclavicular joint data in this analysis, it can be demonstrated that this subject's scapular compensation occurred through increased scapular motion relative to the clavicle at the acromioclavicular joint.

Post-operatively, 5 months after total shoulder arthroplasty, the subject demonstrated considerable improvement in scapulohumeral rhythm. Her post-operative glenohumeral-to-scapulothoracic ratios for the three movements examined neared normal values.

One limitation we encountered was the potential difference in the kinematic data we obtained from surface sensors when compared to the rigidly fixed pin receivers. Our subject was overweight; therefore, we must acknowledge the possibility of surface sensor measurement inaccuracies compared to her pre-operative pin study results. A previous study reviewing both techniques for humeral motion during flexion and scapular plane abduction showed little difference for scapular plane abduction (1%), but more significant differences for rotational

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measurements [9]. Also below 120° of humeral elevation, scapular upward rotation measurements demonstrate small errors with surface sensors [7]. Consequently, the primary finding of alterations in linear motion and scapular rhythm associated with glenohumeral arthritis and subsequent improvement after arthroplasty makes these data valuable. Improved understanding of shoulder motions in the normal and abnormal state could improve implant design, and rehabilitative technique. These data can be used to make perioperative rehabilitation programs address the actual motion abnormalities present in the arthritic shoulder. Furthermore, an understanding of shoulder kinematics may improve assessment of patients with shoulder pathology both before and following shoulder surgery.

Conclusions

In conclusion, we found that shoulder motion differed between a patient with advanced glenohumeral osteoarthritis and healthy individuals. Total shoulder arthroplasty, however, restored the glenohumeral-to-scapulothoracic ratio to normal values. Further research is recommended to quantify the pre-operative and post-operative in vivo kinematics in patients with glenohumeral joint arthritis.

Acknowledgments

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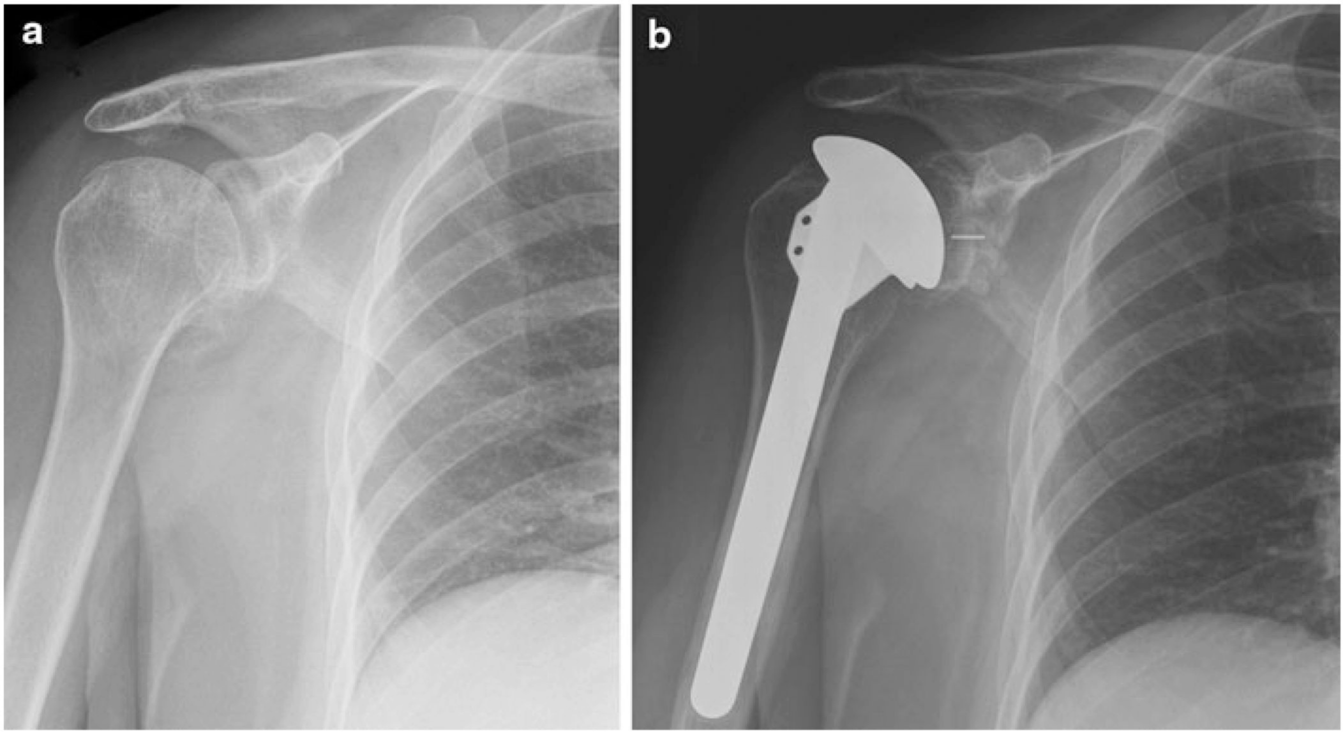

Fig. 1.
Right shoulder AP radiographs: **a** Pre-operative. **b** Post-operative

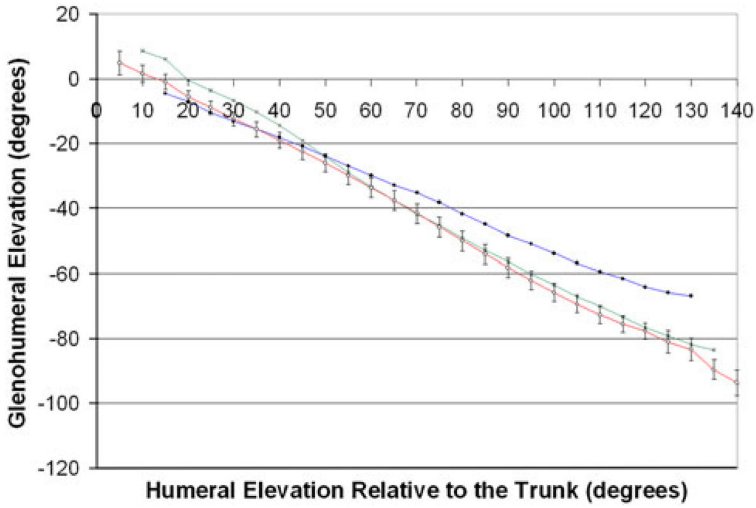

Fig. 2.

Glenohumeral elevation relative to the scapula during average of two trials of arm elevation in flexion. *filled circle* pre-operative pin data (in *blue*), *times* post-operative surface data (in *green*), *open circle* mean and standard error of healthy subject data (n = 12) (in *red*). *Negative values* indicate elevation

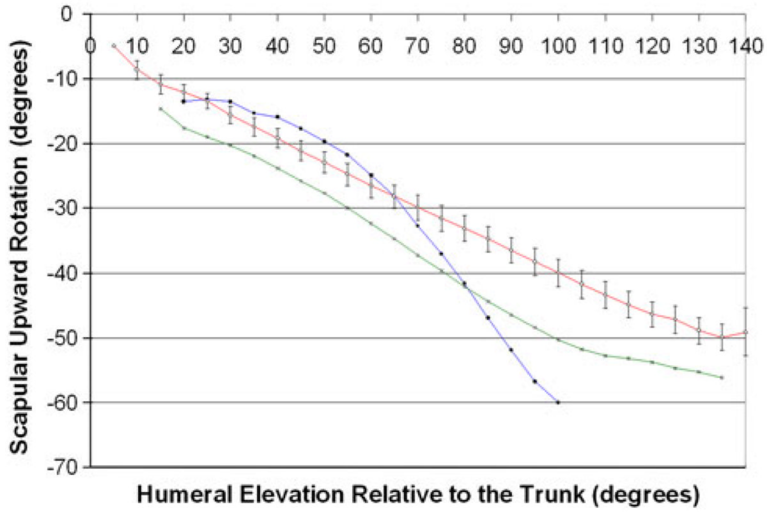

Fig. 3.

Scapular upward rotation relative to the trunk during average of two trials of arm elevation in abduction. *filled circle* pre-operative pin data (in *blue*), *times* post-operative surface data (in *green*), *open circle* mean and standard error of healthy subject data ($n = 12$) (in *red*). *Negative values* indicate upward rotation

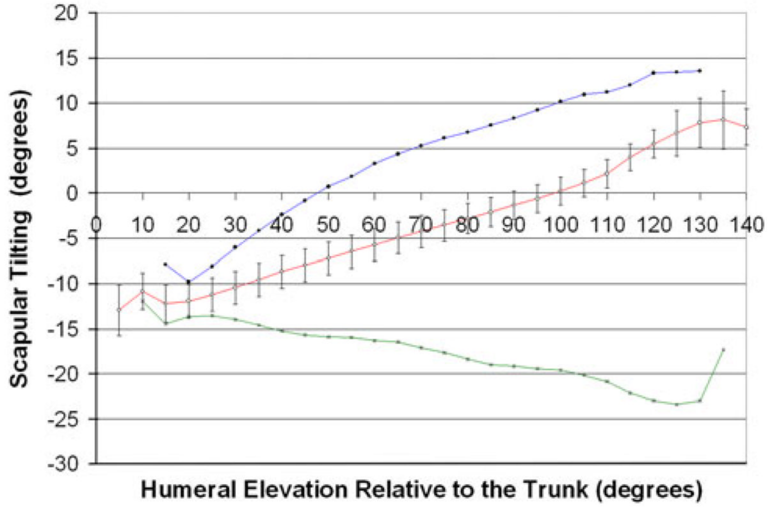

Fig. 4.

Scapular posterior tilting relative to the trunk during average of two trials of arm elevation in flexion. *filled circle* pre-operative pin data (in *blue*), *times* post-operative surface data (in *green*), *open circle* mean and standard error of healthy subject data ($n = 12$) (in *red*). *Positive values* indicate posterior tilt

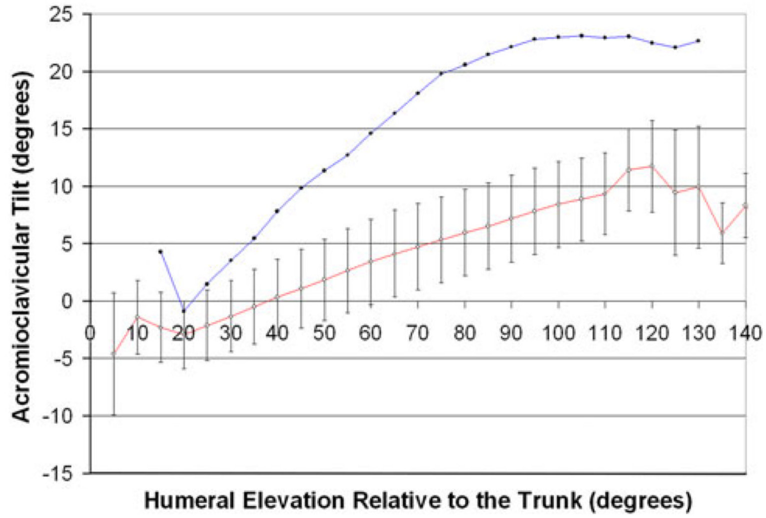

Fig. 5.

Acromioclavicular posterior tilt relative to the clavicle during average of two trials of arm elevation in flexion. *filled circle* pre-operative pin data (in *blue*), *open circle* mean and standard error of healthy subject data (n = 12) (in *red*). *Positive values* indicate posterior tilt

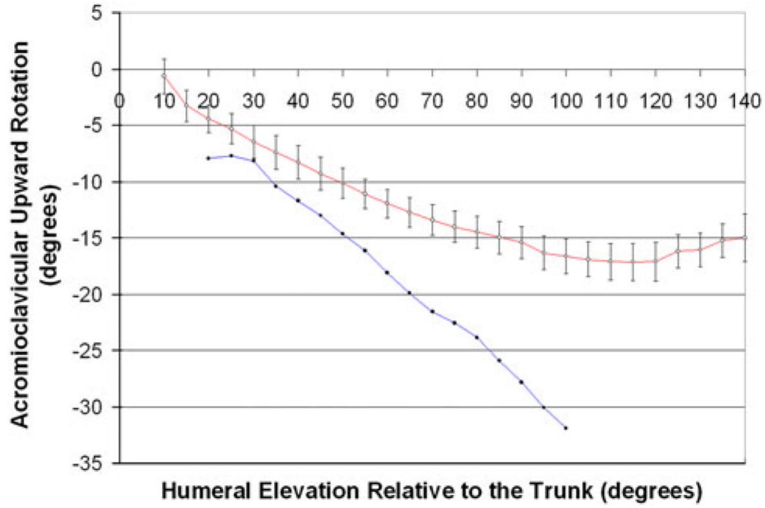

Fig. 6.

Acromioclavicular upward rotation relative to the clavicle during average of two trials of arm elevation in abduction. *filled circle* pre-operative pin data (in *blue*), *open circle* mean and standard error of healthy subject data ($n = 12$) (in *red*). *Negative values* indicate upward rotation

Fig. 7.
Subject with post-operative surface testing of right shoulder during scapular plane abduction. The barrier in front of her serves only to control the plane of scapular elevation. There is no pressure against the wall with elevation

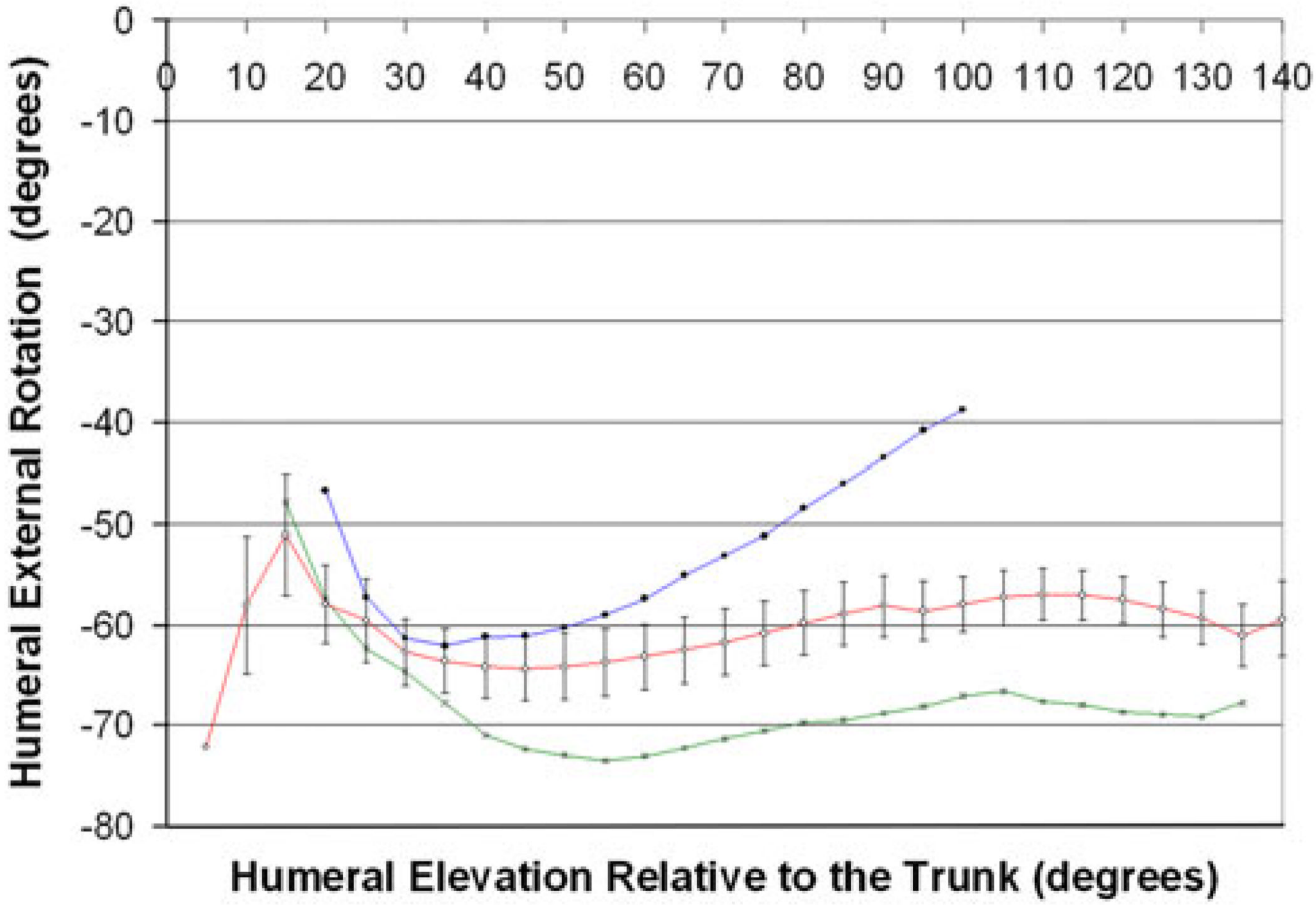

Fig. 8.

Glenohumeral external rotation relative to the scapula during average of two trials of arm elevation in abduction. *filled circle* pre-operative pin data (in *blue*), *times* post-operative surface data (in *green*), *open circle* mean and standard error of healthy subject data ($n = 12$) (in *red*). *Negative values* indicate external rotation