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The effect of a rotator cuff tear and its size on three-dimensional shoulder motion

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ABSTRACT

Background: Rotator cuff-disease is associated with changes in kinematics, but the effect of a rotator cuff-tear and its size on shoulder kinematics is still unknown in-vivo.

Methods: In this cross-sectional study, glenohumeral and scapulothoracic kinematics of the affected shoulder were evaluated using electromagnetic motion analysis in 109 patients with 1) subacromial pain syndrome (n = 34), 2) an isolated supraspinatus tear (n = 21), and 3) a massive rotator cuff tear involving the supraspinatus and infraspinatus (n = 54). Mixed models were applied for the comparisons of shoulder kinematics between the three groups during abduction and forward flexion.

Findings: In the massive rotator cuff-tear group, we found reduced glenohumeral elevation compared to the subacromial pain syndrome (16°, 95% CI [10.5, 21.2], $p < 0.001$) and the isolated supraspinatus tear group (10°, 95% CI [4.0, 16.7], $p = 0.002$) at 110° abduction. Reduced glenohumeral elevation in massive rotator cuff tears coincides with an increase in scapulothoracic lateral rotation compared to subacromial pain syndrome (11°, 95% CI [6.5, 15.2], $p < 0.001$) and supraspinatus tears (7°, 95% CI [1.8, 12.1], $p = 0.012$). Comparable differences were observed for forward flexion. No differences in glenohumeral elevation were found between the subacromial pain syndrome and isolated supraspinatus tear group during arm elevation.

Interpretation: The massive posterosuperior rotator cuff-tear group had substantially less glenohumeral elevation and more scapulothoracic lateral rotation compared to the other groups. These observations suggest that the infraspinatus is essential to preserve glenohumeral elevation in the presence of a supraspinatus tear. Shoulder kinematics are associated with rotator cuff-tear size and may have diagnostic potential.

1. Introduction

Shoulder pain is the most prevalent cause for musculoskeletal upper extremity complaints within our society, and coincides with reduced arm function during activities of daily living and work (Linsell et al., 2006; Picavet and Schouten, 2003). Most shoulder complaints are attributed to pathologic changes in the rotator cuff (RC) (van der Windt et al., 1995). Main clinical entities of RC-disease comprise subacromial pain syndrome (SAPS) and RC-tears (Diercks et al., 2014; van der Windt et al., 1995). The latter is clinically divided for prognostic and therapeutic purposes in isolated supraspinatus tears and massive RC-tears, in which the supraspinatus tear usually extends toward the infraspinatus tendon (i.e. massive posterosuperior RC-tear) (Bedi et al., 2010).

The RC provides essential forces to minimize glenohumeral (GH) translations (i.e. stability) and torques for shoulder motion (Steenbrink et al., 2009; Veeger and van der Helm, 2007). A disturbed equilibrium of RC forces in RC-tears may endanger shoulder stability. Computer and

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cadaver simulations have shown the negative impact of RC-tears involving the supraspinatus and infraspinatus muscle (i.e. massive posterosuperior RC-tears) on joint reaction forces and GH joint stability (Burkhart, 1992; Hansen et al., 2008; Magermans et al., 2004a; Parsons et al., 2002; Steenbrink et al., 2009; Thompson et al., 1996). Clinically, lost GH stability is marked by excessive proximal migration of the humeral head (Henseler et al., 2015). Whereas proximal migration and range of motion are clinically used for diagnostic purposes to diagnose a patient with an RC-tear, the coordination of shoulder motion is generally not assessed. Knowledge on how the extent of an RC-tear affects the coordination of shoulder motion may provide additional diagnostic information. Some research has been done to study kinematics in RC-tears (Mell et al., 2005; Scibek et al., 2008), but those studies do not take into account the effect of tear size when evaluating kinematics. In addition, patients with massive posterosuperior RC-tears have not been extensively studied in 3D motion analyses (Ohl et al., 2015). Consequently, the link between increasing RC-tear size, with a subsequent reduction of infraspinatus forces, and in-vivo shoulder kinematics has still to be determined in order to support experimental findings in simulated RC-tears (McCully et al., 2006).

GH stability and mobility in massive RC-tears may require different kinematics in contrast to the other two clinical subgroups (Steenbrink et al., 2009). GH-joint stability may improve by reduced scapular lateral rotation (i.e. *increased GH elevation*) when the force vector will be directed more toward the center of the glenoid, whereas mobility may improve by increased scapular lateral rotation (i.e. *reduced GH elevation*) as a result of deltoid lengthening (Klein Breteler et al., 1999; Steenbrink et al., 2006; Steenbrink et al., 2009).

The aim of our study was to study the effect of RC-tears and its size on shoulder kinematics by comparing three clinically distinct groups with RC related pain: SAPS (i.e. excluding full-thickness RC-tears (Diercks et al., 2014)), isolated supraspinatus tears and massive posterosuperior RC-tears. We asked: (1) Do patients with massive posterosuperior RC tears exhibit reduced glenohumeral elevation compared to patients with an intact RC (i.e. SAPS) or isolated supraspinatus tear? (2) Is scapulothoracic lateral rotation dissimilar between patients with subacromial pain syndrome (SAPS, i.e. intact RC), an isolated supraspinatus tear or a massive RC tear? We hypothesized that patients with a massive posterosuperior RC-tear would have a reduced contribution of GH elevation (i.e. increased scapular lateral rotation) to the overall elevation compared to patients with SAPS or an isolated tear of the supraspinatus.

2. Methods

2.1. Participants

In this cross-sectional study, shoulder kinematics were evaluated in 109 consecutive patients with RC pathologies, who visited the Laboratory for Kinematics and Neuromechanics (Leiden University Medical Center, Leiden, the Netherlands) between April 2003 and October 2012. Patients were recruited according to one out of three protocols. Based on these protocols, three diagnostic subgroups were selected after a thorough physical examination, AP shoulder radiography and magnetic resonance (MR) arthrography. Each subgroup had its specific inclusion and exclusion criteria:

Group I consisted of thirty-four patients with subacromial pain syndrome (SAPS) with an MR proven intact RC, who were recruited at the outpatient clinic of three regional hospitals (Leiden University Medical Center, Medical Center Haaglanden and Alrijne Hospital) (Diercks et al., 2014). SAPS was clinically defined by a positive Hawkins and Neer impingement test in combination with at least one of the following clinical signs of SAPS: pain during shoulder movements, pain at night or incapable of lying on the shoulder, painful arc, diffuse pain at palpation of the greater tuberosity, scapular dyskinesis, a positive full/empty can test or a positive Yocum test. Only patients aged between 35 and 60 years with unilateral shoulder complaints for at least 3 months were included. Exclusion criteria were insufficient Dutch language skills, prior shoulder surgery, shoulder fracture or dislocation, radiculopathy, frozen shoulder, electronic implants, (inflammatory) GH or symptomatic acromioclavicular osteoarthritis, calcific tendinitis, full-thickness RC-tear, PASTA lesion, labrum or ligament pathology, pulley lesion, biceps tendinopathy, os acromiale and tumor.

Group II consisted of twenty-one patients with an isolated full-thickness and degenerative supraspinatus tear who were included at the Medical Center Haaglanden when suffering from impaired function and pain (i.e. Davidson type I or II) (Davidson et al., 2005). All patients were scheduled for surgical RC repair and the extent of RC-tears was intra-operatively confirmed.

Group III consisted of fifty-four patients with a massive posterosuperior RC-tear recruited at two hospitals (Leiden University Medical Center and Medical Center Haaglanden). A massive posterosuperior RC-tear was defined according to the criteria of Davidson et al. as type 3 full-thickness posterosuperior tear, with a tear width of ≥ 20 mm, a length of ≥ 20 mm, and partial or complete detachment of the infraspinatus insertion side (Davidson et al., 2005). The teres minor muscle was intact in all participants. Patients suffered from either pain or impaired shoulder function during activities of daily living.

Exclusion criteria in group II and III were: insufficient Dutch language skills, a history of shoulder surgery, fracture or dislocation, radiculopathy, subscapularis tear, reduced passive RoM (clinically determined by comparing the affected to unaffected shoulder), muscle dystrophy, (inflammatory) symptomatic GH or acromioclavicular osteoarthritis, tumor and electronic implants.

Baseline characteristics are presented in Table 1. Patients may have participated in earlier studies (de Witte et al., 2013; Kolk et al., 2015, 2016; Steenbrink et al., 2006; Steenbrink et al., 2010a; Steenbrink et al., 2010b). The medical ethics committees of Leiden University Medical Center (P07.123 & P09.227) and Zuidwest Holland (P07.116) approved all examinations. Written informed consent was obtained from all participants.

2.2. Measurement set-up

Kinematics in affected shoulders were evaluated in a standardized seated position with the Flock of Birds (FoB) 3D electromagnetic tracking system (Ascension Technology Inc., Milton, Vermont, USA). An extended range transmitter generated an electromagnetic field to record the position and orientation of seven wired sensors at about 30 Hz in order to examine bilateral shoulder motion with six degrees of freedom. Motion of the shoulder girdle was recorded with three wired sensors attached to both arms. One sensor was adhered to the flat cranio-lateral surface of the acromion with self-adhesive tape. Other sensors were attached to the flat surface of the distal humerus and the dorsal side of the distal forearm with a Velcro strap. The seventh sensor was attached to the manubrium sternii with self-adhesive tape. Subsequently, twenty-four bony landmarks were manually palpated and digitized as recommended by the International Society of

Table 1
Baseline characteristics.

Characteristics	SAPS (n = 34)		Supraspinatus tear (n = 21)		Massive RC-tear (n = 54)	
Age (yrs., SD)	50	(6)	58	(9)	61	(7)
Female (n, %)	19	(56)	12	(57)	20	(37)
Left side affected, (n, %)	14	(41)	10	(48)	19	(35)
Dominant side affected (n, %)	21	(62)	11	(52)	35	(65)
VAS for pain during movement (mm, SD)	39	(24)	59	(31)	47	(27)