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Technical and measurement report

Distance between rotator cuff footprints and the acromion, coracoacromial ligament, and coracoid process during dynamic arm elevations: Preliminary observations

Fabien Dal Maso [a, b, *], Yoann Blache [a, b], Maxime Raison [b, c], Anton Arndt [d, e], Mickaël Begon [a, b]

[a] Département de kinésiologie, Université de Montréal, 2100, boul. Édouard-Montpetit, Montréal, QC, H3T 1J4, Canada
[b] Centre de recherché du CHU Ste Justine, 3175 Chemin de la Côte-Sainte-Catherine, Montréal, QC, H3T 1C4, Canada
[c] Ecole Polytechnique de Montréal, 2900 boul. Édouard-Montpetit, Montréal, QC, H3T 1J4, Canada
[d] Karolinska Institutet, Solnavägen 1, 171 77 Solna, Sweden
[e] The Swedish School of Sport and Health Sciences, Lidingövägen 1, 114 33 Stockholm, Sweden

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ABSTRACT

Background: The objective of this study was to provide preliminary measures of the distance between the supraspinatus, infraspinatus, and subscapularis footprints and the acromion, coracoacromial ligament, and coracoid process, during dynamic arm elevations through the entire range-of-motion.
Methods: Two healthy men performed maximum adduction, flexion, abduction, and extension with the arm internally, neutrally, and externally rotated. The distance between each rotator cuff footprint and the acromion, coracoacromial ligament, and coracoid process was measured from glenohumeral kinematics obtained from markers fitted to intracortical pins combined with the scapular and humeral 3D geometry obtained from CT-scan.
Results: All footprints moved to be less than 10 mm to the acromion, coracoacromial ligament and coracoid process. They got closer to the acromion than to the other parts of the coracoacromial arch. The acromion-supraspinatus and acromion-infraspinatus distances were minimal during abduction and flexion. The acromion-subscapularis distance was minimal when the arm was in external and neutral rotation during both adduction and flexion.
Conclusions: The present study provides benchmark results of the distance between the rotator cuff footprints and the coracoacromial arch that may guide future clinical research. Pressure transducers should be positioned throughout the coracoacromial arch to provide comprehensive assessment of the compression undergone by the rotator cuff tendons. Common shoulder examination tests, that require flexion and internal rotation movements, may be refined since the supraspinatus footprint was the closest to the coracoacromial arch during abduction. Larger scale investigations may be needed to identify more accurate shoulder examination tests.

1. Introduction

Rotator cuff pathologies affect up to 50% of people over 60 years (Sher et al., 1995). A reduced distance between the humeral head and the acromion, *i.e.* acromiohumeral distance, occurring during arm elevation (Bey et al., 2007; Giphart et al., 2012; Dal Maso et al., 2016) has been associated with an increase in rotator cuff tendon compression (Hawkins and Kennedy, 1980; Poitras et al., 2010). Although controversial (Lewis, 2015), the repetition of compressions may cause subacromial impingement, which is believed to make part of the etiologic factors leading to rotator cuff tear (see Seitz et al. (2011) for a review).

The acromiohumeral distance is usually determined by measuring the shortest distance between any parts of the humerus and the acromion (Bey et al., 2007; Giphart et al., 2012; Dal Maso et al., 2016). These studies reported that the shortest

* Corresponding author. Département de kinésiologie, Université de Montréal, 2100, boul. Édouard-Montpetit, Montréal, QC, H3T 1J4, Canada. Tel.: +1 514 343 6111x44017; fax: +1 514 343 2181.
E-mail address: fabien.dalmaso@gmail.com (F. Dal Maso).

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acromiohumeral distance occurred from 35° to 70° of glenohumeral elevation and that the humeral head greater tuberosity, *i.e.* area of the supraspinatus tendon insertion (termed as footprint), got closer to the acromion than any other part of the humeral head. However, as rotator cuff footprints surround the humeral head, the knowledge provided by previous investigation based on the current method to characterize the subacromial space is not specific to rotator cuff footprints. An in-depth analysis of the distance above the supraspinatus, infraspinatus, and subscapularis footprints is fundamental to better understand the etiology of rotator cuff tendinopathy.

Although the edge of the acromion has been identified as the predominant site of rotator cuff tendon compression (Lee et al., 2001; Yamamoto et al., 2009), in some cases, the coracoacromial ligament (Burns and Whipple, 1993; Delforge et al., 2014), and the coracoid process (Okoro et al., 2009; Martetschlager et al., 2012) are also involved in rotator cuff tendons impingement. Therefore, the assessment of the distance between rotator cuff footprints and the tissues forming the coracoacromial arch, *i.e.* acromion, coracoid process, and coracoacromial ligament, is required to provide a comprehensive and accurate assessment of the potential risk of impingement during arm movements.

The objective was to provide preliminary measures on the distance between the supraspinatus, infraspinatus and subscapularis footprints and the acromion, coracoacromial ligament, and coracoid process during dynamic arm elevations through the entire arm range-of-motion. With regard to previous studies (Bey et al., 2007; Giphart et al., 2012; Dal Maso et al., 2016), it was hypothesized that the supraspinatus footprint would get closer to the acromion than the other rotator cuff footprints. Also, since the rotator cuff footprints surround the humeral head, it was suggested that arm elevation in different planes and axial rotations may alter the distance between each rotator cuff footprint and the acromion, coracoacromial ligament, and coracoid process.

2. Methods

Data collection and processing are fully described in Dal Maso et al. (2016). Briefly, the study was approved by the Karolinska Institute (Sweden) and the University of Montreal (Canada) ethics committees. Pins were inserted into the left scapula and humerus of two right-handed healthy men (P1: 27 years; 1.65 m; 57 kg and P2: 44 years; 1.77 m; 82 kg) under standard surgical conditions. The non-dominant side was tested in order to avoid detrimental discomfort in the participants' dominant arm during their professional practice the days following the experiment. The trajectories of reflective markers secured to pins and positioned on the thorax were acquired with 18 VICON™ cameras (Oxford Metrics Ltd., Oxford, UK). The scapula and the humerus geometry was obtained from computed tomography scanner measurements (General Electric Medical System, Milwaukee, USA) while the participants were fitted with the pins and markers.

From a relaxed position with the arm at the side, participants performed arm adduction, flexion, abduction, and extension with the arm successively internally, neutrally, and externally rotated. The elbow was kept extended throughout the elevations. Participants were instructed to maintain self-moderate speed throughout elevations. One trial was recorded in each experimental condition. The glenohumeral and thoracohumeral kinematics were reconstructed using local optimization (Monnet et al., 2012) with three translations and three rotations (plane of elevation – elevation – axial rotation sequence). Zero degree of glenohumeral and thoracohumeral elevation angle corresponds to the rest position (Jackson et al., 2012). The error was less than 0.15 mm and 0.2° for translation and rotation (Dal Maso et al., 2014).

The footprint locations of the supraspinatus, infraspinatus, and subscapularis on the humeral head were identified manually by an experimenter using landmarks established in cadaver specimens (Curtis et al., 2006; Mochizuki et al., 2009) (Fig. 1). The area of the supraspinatus footprints was 2.3 cm^2 (P1 and P2), 2.7 cm^2 (P1) and 2.9 cm^2 (P2) for the infraspinatus, and 3.1 cm^2 (P1) and 3.4 cm^2 (P2) for the subscapularis. The teres minor footprint was not considered since this tendon is less at risk of subacromial impingement syndrome than the other rotator cuff muscles (Shah et al., 2008). The coracoacromial ligament was modeled by finite elements using the Catia® software (Seo et al., 2012) after manual identification of its footprints on the acromion and the coracoid process (Fig. 1).

At each time frame the triangle centroids of the bone parts of interest and the coracoacromial ligament were positioned according to their respective previously determined kinematics. The 3D Euclidean distances between all triangle centroids of each rotator cuff footprint and the acromion, coracoacromial ligament, and coracoid process were calculated. The minimal distance measured throughout each movement between each rotator cuff footprint and the acromion, coracoacromial ligament, and coracoid process was reported. Also, the minimal distance between each rotator cuff footprint and the acromion according to the thoracohumeral angle was illustrated. Due to the small sample size ($n = 2$), the results was presented in the form of descriptive analysis.

3. Results

In the rest position, the supraspinatus and infraspinatus footprints were closer to the acromion than the coracoacromial ligament and the coracoid process (Table 1). The subscapularis footprint was equidistant to the acromion, coracoacromial ligament, and coracoid process. All distances were greater than 15 mm.

During all the movements, the supraspinatus footprint got closer to the acromion (range between 0.5 mm and 15.7 mm, 6.1 mm on average) than the infraspinatus (range between 3.3 mm and 19.1 mm, 10.7 mm on average) and subscapularis (range between 1.1 mm and 31.9 mm, 13.9 mm on average) footprints (Table 1). On average, the infraspinatus footprint got closer to the acromion during abduction (3.9 mm for P1 and 5.5 mm for P2) than during flexion (8.7 mm for P1 and 13.1 mm for P2) and adduction (13.4 mm for P1 and 11.9 mm for P2) (Table 1). On average, the subscapularis footprint got closer to the acromion during adduction (6.6 mm for P1 and 3.9 mm for P2) and flexion (7.4 mm for P1 and 9.2 mm for P2) than during abduction (14.8 mm for P1 and 21.4 mm for P2) (Table 1).

The supraspinatus and infraspinatus footprints got closer to the acromion than to the coracoacromial ligament and coracoid process. During adduction, flexion, and abduction the shortest acromio-supraspinatus distance ranged between 0.5 mm and 7.5 mm (3.8 mm on average). The coracoacromial ligament-supraspinatus distance was less than 7.5 mm in 5 out of 17 cases (range between 2.1 mm and 30.0 mm, 12.0 mm on average) and the coracoid process-supraspinatus distance remained beyond 9.5 mm (Table 1). The acromio-infraspinatus distance ranged between 3.3 mm and 19.1 mm (9.6 mm on average). The coracoacromial ligament-infraspinatus distance was less than 9.6 mm in 7 out of 17 cases (range between 5.0 mm and 38.7 mm, 22.1 mm on average), and the coracoid process-infraspinatus distance remained beyond 23.5 mm (Table 1). Only the subscapularis footprint got closer to the coracoacromial ligament and the coracoid process than to the acromion. This was observed during the rest position, elevations with the arm internally rotated, and abduction and extension with the arm neutrally rotated (see bolded values in Table 1).

Since the rotator cuff footprints got closer more often to the acromion than to the coracoacromial ligament and the coracoid