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ORIGINAL ARTICLE

The effect of scapular position on subacromial contact behavior: a cadaver study

Takayuki Muraki, PT, PhD[a], Nobuyuki Yamamoto, MD, PhD[a], John W. Sperling, MD, MBA[b], Scott P. Steinmann, MD[b], Robert H. Cofield, MD[b], Kai-Nan An, PhD[b,]*

[a]*Biomechanics Laboratory, Division of Orthopedic Research, Mayo Clinic, Rochester, MN, USA*
[b]*Department of Orthopedic Surgery, Mayo Clinic, Rochester, MN, USA*

Background: Patients with subacromial impingement were reported to show abnormal scapular positions during shoulder elevation. However, the relationship between the scapular positions and subacromial impingement is unclear. The purpose of this study was to biomechanically determine the effect of scapular position on subacromial contact behavior by using fresh frozen cadavers.
Methods: The peak contact pressure on the coracoacromial arch was measured with a flexible tactile force sensor in 9 fresh frozen cadaver shoulders. The measurement was performed during passive glenohumeral elevation in the scapular plane ranging from 30° to 75°. The scapular downward and internal rotations and anterior tilt were simulated by tilting the scapula in 5° increments up to 20°. The measurement was also performed with combination of scapular downward and internal rotations and anterior tilt positions.
Results: The peak contact pressure decreased linearly with anterior tilt, and a significant difference between neutral scapular position (1.06 ± 0.89 MPa) and anterior tilt by 20° (0.46 ± 0.18 MPa) was observed ($P < .05$). However, the scapular positioning in the other directions did not change the peak contact pressure significantly. Furthermore, any combination of abnormal scapular positions did not affect peak contact pressure significantly.
Conclusion: Scapular anterior tilt decreased peak contact pressure during passive shoulder elevation. In addition, scapular downward and internal rotations had little effect on peak contact pressure. The abnormal scapular motion reported in previous studies might not be directly related to symptoms caused by subacromial impingement.
Level of evidence: Basic Science Study; Biomechanics

Keywords: Cadaver; contact pressure; passive shoulder motion; scapular position; shoulder; subacromial impingement

Subacromial impingement syndrome is a common shoulder disease characterized by pain during shoulder motion, particularly elevation. Previous studies reported several etiologic factors that cause subacromial impingement.[3,7] One of the factors that have been observed in patients with subacromial impingement is alternation in scapular motion pattern during shoulder elevation. In healthy individuals, the scapula upwardly and externally rotated and posteriorly tilted during shoulder elevation.[10,15,21] Several

Institutional Review Board approval is not required for cadaveric studies.

*Reprint requests: Kai-Nan An, PhD, Biomechanics Laboratory, Division of Orthopedic Research, Mayo Clinic, 200 First Street SW, Rochester, MN 55905, USA.

E-mail address: an.kainan@mayo.edu (K.-N. An).

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studies reported that 1 or all of these motions were reduced in patients with subacromial impingement syndrome.[5,10,13]

In spite of several reports regarding altered scapular motions in patients with subacromial impingement, whether those alternations indicate the cause or result of impingement is still unclear. Solem-Bertoft et al[20] reported that subacromial space in scapular protraction position, which seemed to represent internal rotation and anterior tilting, was narrower than that in scapular retracted position, which seemed to consist of external rotation and posterior tilting. However, the measurement of the subacromial space was performed in the arm alongside the body. Subacromial impingement is speculated to occur not at the initial range but in the middle range because the minimal acromiohumeral distance occurs near 90° of humerothoracic elevation.[2,6] Therefore, subacromial space or contact should be in the middle range of elevation as well.

In a previous cadaver study, Karduna et al[8] determined the effect of scapular orientation on subacromial space at maximum internal rotation and 90° of humerothoracic elevation. Scapular upward and downward rotations reduced and increased subacromial space, respectively, whereas no change of the space was shown with scapular external and internal rotations and posterior and anterior tilts.[8] Although this study provided a key to clarify the significance of the alternation in scapular position in patients with subacromial impingement, more details of subacromial contact, including pressure and location during dynamic motion, are needed because the measurement was performed in a static shoulder position and subacromial contact pressure was proved to occur throughout shoulder elevation.[23]

The purpose of this cadaveric study was to determine the relationship between scapular position and subacromial contact behavior during dynamic passive shoulder elevation. We hypothesized that subacromial peak contact pressure would increase with each abnormal scapular motion, such as downward rotation, internal rotation, anterior tilting, and combination of these 3 motions. In clinical relevance, the peak contact pressure is a mechanical factor indicating degree of the impingement. The knowledge of the relationship between scapular position and subacromial peak contact pressure is useful to evaluate how the mechanical factor affects symptom in the patient with subacromial impingement syndrome when observing the scapular position.

Materials and methods

Preparation of specimens

Nine fresh frozen cadaveric shoulder joints (4 left and 5 right shoulders) were harvested for this study. The mean age of the specimens was 76 years (standard deviation, 16; range, 52-99). Specimens with a macroscopic rotator cuff tear, severe joint contracture, or radiographic evidence of glenohumeral osteoarthritis were excluded. The specimens were preserved at −20°C in a freezer. Thawing of the specimens at room temperature (24°C) started approximately 15 hours before the experiment. All soft tissues except the rotator cuff muscles, subacromial bursa, and coracoacromial ligament were removed without venting the glenohumeral joint capsule. The humerus was amputated at approximately 150 mm distal from the surgical neck. A fiberglass rod with a protractor was inserted into the medullary canal of the humeral shaft and cemented. A custom-designed shoulder experimental device consisting of fiberglass and plastic was used for 3-dimensional motion analysis with an electromagnetic field[17] (Fig. 1, *A*). In this device, the scapula was mounted on a jig plate capable of tilting anteriorly in 5° increments (Fig. 1, *B*). The distal part of the humeral rod was put between 2 semicircular arch frames capable of moving in the horizontal plane so that the rod vertically moved along the frames. This setting also allowed the axial rotation of the humeral rod. Three strings were sewn to the supraspinatus, subscapularis, and infraspinatus/teres minor tendons. A compressive force of 22 N, which was the minimum force to avoid subluxation of the humeral head, was applied to the glenohumeral joint by pulling the 3 strings with dead weights.[22] The supraspinatus, subscapularis, and infraspinatus/teres minor tendons were loaded with 3.5 N, 10 N, and 8.5 N, respectively. These forces were calculated on the basis of the physiologic cross-sectional area of the 3 muscles.[1] In this setting, there was no dislocation or subluxation in macroscopic observation when glenohumeral elevation was performed before measurement. Saline was sprayed on the specimens about every 10 minutes throughout the experiment to avoid dehydration of the tissues.

Instrumentation

To quantify and visualize subacromial contact behavior, a flexible tactile force sensor (K-Scan model 4000; Tekscan, Inc., South Boston, MA, USA), which is paper thin (0.1 mm), was used in this study. This sensor is composed of 2 independent sensing regions with a matrix width and height of 28 × 33 mm. These 2 regions were placed side by side and then taped with transparent tape to cover most of the coracoacromial arch. The connected sensors were inserted between the coracoacromial arch and rotator cuff. They were then fixed to the arch with threads. One region was located underneath more than one-third of the acromion from the anterior edge (acromion region), and the other region was located underneath more than two-thirds of the coracoacromial ligament (coracoacromial ligament region) (Fig. 1, *C*). This setting allowed concurrent measurement of contact pressures on both regions underneath the coracoacromial arch (total region).

The sensitivity level ranged from 0.15 to 10.36 MPa and was chosen according to results from a preliminary study. In this activity level, calibration was performed before the measurement. This setting offered 3.9% ± 2.2% of the accuracy and 1.3% ± 0.3% of the repeatability.[17] The peak contact pressure and contact location recorded by the tactile force sensor were analyzed with I-Scan software version 5.0 (Tekscan, Inc.).

Glenohumeral joint angle was monitored and measured with an electromagnetic tracking system (3SPACE FASTRAK; Polhemus, Inc., Colchester, VT, USA) and accompanying software (MotionMonitor; Innovative Sports Training Inc., Chicago, IL, USA). This device enables the measurement of the 3-dimensional position and orientation of the sensors relative to the absolute coordination generated by the source. An attachment of the sensor for the scapula was secured to the transition part between the acromion and scapular spine to avoid interference to the contact pressure measurement underneath the acromion. Another attachment of the sensor for the