THE NORMAL PATTERN OF THREE-DIMENSIONAL SCAPULAR KINEMATICS

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INTRODUCTION Scapular motion is an important biomechanical consideration with respect to shoulder pathologies, such as impingement syndrome and glenohumeral instability. Traditionally, rotations of the scapula have been studied in two dimensions, so that only one rotation was considered[1,2]. This rotation was about an anterior/posterior axis perpendicular to the plane of the scapula. Although there have been several recent investigations of scapular three-dimensional motion, they have been static measurements[3,4]. The objective of the present study is to describe the normal three-dimensional motion patterns of the scapula under dynamic conditions.

METHODS Subjects After obtaining approval from this institution's human subjects review board, eight healthy volunteers (mean age = 33 years) were recruited for this study. An electromagnetic tracking device (Polhemus 3Space Fastrak, Colchester, VT) was used to capture the rotational motions of the scapula and humerus with respect to the thorax. Motions of the thorax and humerus were monitored with simple surface mounted receivers. Motion of the scapula was monitored with a bone fixed receiver. Two 1.6 mm K-wires were rigidly drilled directly into the lateral aspect of the subject's scapular spine and a plastic alignment jig coupled the pins and receiver so that motion of the scapula was directly reflected by motion of the receiver.

Kinematics The arbitrary axes defined by the Polhemus were converted to anatomically appropriate axes derived from digitized bony landmarks. After the digitization process, the raw data from the Polhemus were converted into anatomically defined rotations and displayed in real time in LabView (National Instruments, Austin, TX). Motion of the humerus was described using an Euler angle sequence consisting of the plane of elevation, amount of elevation and internal/external rotation. Motion of the scapula was described with an Euler angle sequence defined with respect to scapular axes as follows:

- 1st rotation - internal/external rotation about a superior/inferior axis
- 2nd rotation - upward/downward rotation about an anterior/posterior axis
- 3rd rotation - anterior/posterior tilting about a medial/lateral axis

Protocol Subjects stood with their feet at a comfortable width apart, heels against a rigid support and eyes fixed forward. The experimental protocol consisted of active elevation of the humerus in the scapular plane (40 degrees anterior to the frontal plane) with the elbow in full extension. Since the subject was facing forward and could not observe their arm or the computer monitor, a series of practice trials were performed, in which the investigator was monitoring the plane of elevation on the computer and providing the subject with verbal feedback. Once the subject could accurately reproduce this motion, data collection began. Subjects maximally elevated their arm in the scapular plane to a count of three and then adducted along the same path, with data collected continuously at a rate of approximately 10 Hz for three consecutive trials. For each trial, the minimum and maximum elevation points were calculated and the rest of the data were interpolated in five-degree increments of elevation. These data were then averaged over the three trials. Both scapular and humeral rotations were measured with respect to the thorax.

RESULTS The mean and standard deviation of humeral elevation for all subjects was 11 +/- 5 degrees at the start of the motion and 149 +/- 9 degrees at the end range of motion. All subjects demonstrated the same pattern of upward rotation (49 +/- 5 degrees), posterior tilting (32 +/- 12 degrees) and external rotation (26 +/- 13) over the full range of motion. There were several differences in the patterns amongst the three rotations (Fig 1). Upward rotation exhibited the same trend observed in two-dimensional studies, with a progressive increase in upward rotation as the humerus was elevated. There was a small setting phase between the minimum elevation and 30 degrees of elevation for which little upward rotation was noted. External rotation also exhibits this setting phase up to approximately 90 degrees of elevation, after which there was a sharp increase in the amount of external rotation. Although there wasn't a similar setting phase for posterior tilting, there was an increase in the rate of rotation at about 90 degrees of elevation.

DISCUSSION This is the first study to present an accurate representation of three-dimensional scapular kinematics during a continuous arc of motion. This accuracy was ensured by drilling pins directly into the scapula. It has been demonstrated in the present study that although upward rotation represents the largest range of motion, the other two rotations are substantial. It is clear that scapular motion is far more complex than can be represented by a two-dimensional description of motion. These rotational patterns may have important consequences in the development of shoulder models that attempt to predict joint reaction forces. These results may also help in the understanding of shoulder pathologies in which kinematic patterns may be altered.

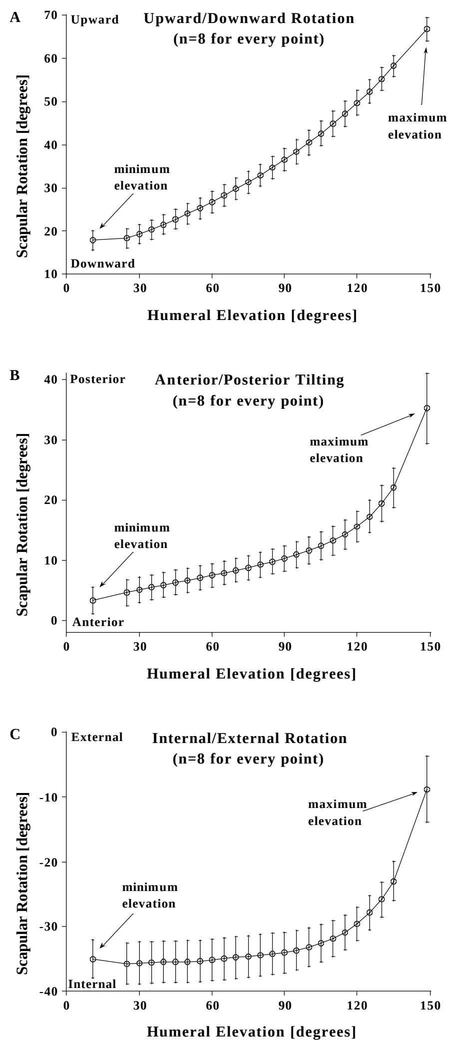

Figure 1 Plots of scapular rotation vs. humeral elevation (mean +/- sem). All rotations are with respect to the thorax.
A) Upward Rotation, B) Posterior Tilting, C) External Rotation

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