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Kinematic analysis of scapulothoracic movements in the shoulder girdle: a whole cadaver study

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A R T I C L E I N F O

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Shoulder girdle
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Level of evidence: Basic Science Study; Kinesiology

Background: Existing kinematic studies of the shoulder girdle focus on humerothoracic movements. Isolated scapulothoracic movements are also performed during daily activities and rehabilitation but kinematic values are lacking.

Methods: A kinematic analysis was performed in 14 cadaveric shoulders during protraction, retraction, and shrug. An optical navigation system was used to analyze sternoclavicular, scapulothoracic, and acromioclavicular motions.

Results: In the sternoclavicular joint, shrug and retraction caused a posterior clavicular rotation of 5° (standard deviation [SD] 6°) and 3° (SD 2°), while protraction induced an anterior rotation of 3° (SD 2°). Shrug caused a large clavicular elevation of 25° (SD 5°). Shrug and retraction caused an increase in retraction of 17° (SD 5°) and 9° (SD 2°). Protraction induced an increase of 10° (SD 2°) toward protraction. In the scapulothoracic joint, shrug induced an increase of 3° (SD 2°) in anterior scapular tilt, and a lateral rotation of 26° (SD 4°). Retraction caused a lateral rotation of 4° (SD 3°). Protraction caused an increase of 7° (SD 2°) in the scapular protraction position, while shrug and retraction demonstrated a decrease of 9° (SD 2°) and 6° (SD 5°). In the acromioclavicular joint, posterior tilting of the scapula compared to the clavicle increased 23° (SD 6°) during shrug, while during protraction an increase of only 4° (SD 3°) was seen. During shrug, relative lateral rotation increased 13° (SD 4°). The protraction movement decreased the relative protraction position with 3° (SD 2°).

Conclusion: This study provided normative kinematic values of scapulothoracic movements in the shoulder girdle.

Over the years, researchers have tried to unravel the kinematics of the shoulder girdle during movements.[3-5,9-12,14-17] Classically, sensors are attached to the skin on the thorax, clavicula, scapula, and upper arm to perform a noninvasive kinematic evaluation of the movement of the shoulder girdle. However, the registration of joint motions through bone-anchored clusters is considered to be more accurate because of inevitable skin motion artifacts associated with the usage of skin sensors.[6] Although these studies are mostly carried out on cadaveric specimens, some researchers have even used transcortical pins to investigate the kinematics in vivo in healthy subjects.[4,5,7,10-12]

In these protocols, mostly humerothoracic movements are investigated. Hereby, coronal plane elevation, sagittal plane elevation, elevation in the scapular plane, and horizontal adduction are frequently examined. More recently, also fluoroscopic imaging has been used to investigate mainly scapular and glenohumeral joint.[8,13] Unfortunately, while the scapula and humerus can be easily identified on fluoroscopy and matched with computed tomography images, it is very difficult to analyze clavicular rotations. Sternoclavicular and acromioclavicular joint motions are therefore difficult to analyze using this technique.[7]

Currently, only limited studies have been performed on isolated scapulothoracic (ST) movements such as protraction, retraction, and shrug.[4,5,11] However, these movements are also frequently performed often during daily activities and rehabilitation exercises. Moreover, these ST movements could be severely influenced and cause pain in shoulder pathology such as clavicular fractures, acromioclavicular joint injuries, or SICK scapula syndrome.[1] In contrast to humerothoracic movements, during these isolated ST

The Ethics Committee of the University hospital of Ghent gave approval for the study (BC-08175).

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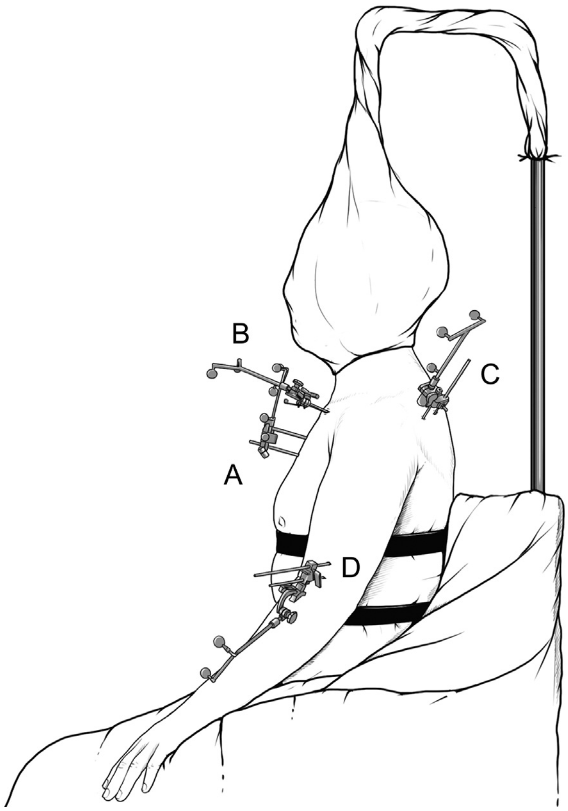

Figure 1 Whole cadaver setup with the sitting position of the cadaver and transcortical pins with the position of the markers into the sternum (A), the lateral third of the clavicle (B), the scapular spine (C), and on the lateral aspect of the humerus distal to the deltoid attachment (D).

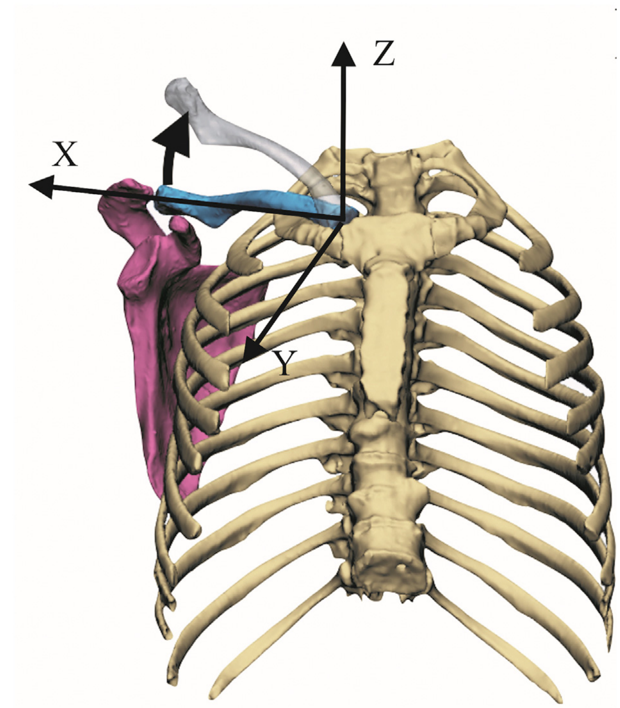

Figure 2 Illustration of the SC coordinate system as defined in Visual 3D showing clavicle elevation around Y axis.

movements, the glenohumeral joint is excluded from the motion analysis, which might result in different values for the joint motions of the shoulder girdle. Therefore, in this whole cadaver study, a kinematic analysis of 3 scapulothoracic movements was performed providing normative values for sternoclavicular, scapulothoracic, and acromioclavicular joint motions.

Methods

Subjects

Fourteen shoulders from 8 fresh frozen cadavers (5 male, 3 female, mean age 85 years, mean length 172 cm, and mean weight 70 kg) were used. The Ethics Committee of the University hospital of Ghent gave approval for the study (BC-08175). Prior to the experiment, available cadavers were screened using computed tomography. Specimens with severe degenerative changes such as joint space narrowing, joint subluxation, major osteophytes or geodes in either the sternoclavicular (SC), acromioclavicular (AC), or glenohumeral joints were not withheld. One shoulder was excluded from analysis because of a humeral fracture limiting the range of motion; another shoulder was excluded because of a history of clavicular fracture and plating.

Data collection device

An optical navigation system (OptiTrack FLEX 13; NaturalPoint, Corvallis, OR, USA) with 10 infrared cameras and motion capture software (OptiTrack Motive 1.10.0; NaturalPoint, Corvallis, OR, USA) was used. The sampling rate of the system was 100 Hz, with a tracking error of maximum 0.7 mm. Transcortical pins were placed into the sternum, the lateral third of the clavicle, the scapular spine, and on the lateral aspect of the humerus distal to the deltoid attachment. On each pin, 3 passive markers were attached in order to capture the segment in 3-dimensional. No reflections of the pins were visible during the measurement.

Experiment protocol

The setup was based on the protocol of Oki et al.[14] Whole cadavers were used to allow physiologic shoulder motion. The cadavers were placed on a table in a sitting position and hung upright on a steel pole (Fig. 1). Additional stabilization was done using multiple tensioning straps around the waist and lower half of the thorax. Particular attention was given to ensure free scapular motion. Before the experiment, the arms of the cadavers were manually mobilized 5 times in all planes to release possible contractures of the shoulder. After a pointer calibration, anatomical landmarks of the cadavers were digitized as specified by the International Society of Biomechanics.[18] Three-dimensional kinematics of the sternoclavicular, acromioclavicular, and scapulothoracic joints were measured. Three movements were analyzed: (1) protraction, (2) retraction, and (3) shrug. Protraction and retraction movements were performed by holding the acromion and proximal humerus in one hand and applying force in an anterior and posterior direction, respectively, while the arm was hanging at the side. For the shrug movement, the elbow was kept in 90° of flexion by holding the arm just distally of the elbow joint and the shoulder was held in neutral rotation. The movement was performed by applying a superiorly directed force as much as possible. Each movement was done in a fluent motion (6 seconds) through the entire range of motion (RoM) and repeated 6 times.

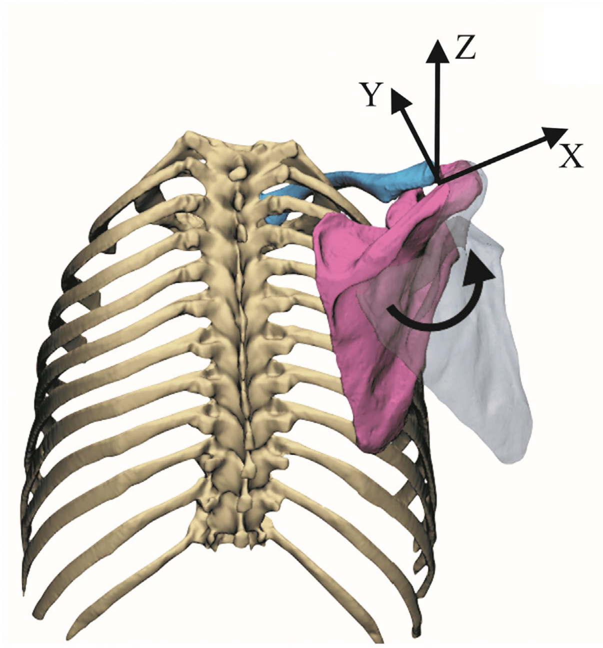

Figure 3 Illustration of the ST coordinate system as defined in Visual 3D showing lateral rotation of scapula around Y axis.

Furthermore, the sequence of the movements was randomized for each shoulder.

Data reduction and analysis

Each trial was labeled within OptiTrack Motive 1.10.0 and exported to a c3d file for further data processing within Visual 3D (v6.05.01; C-Motion Inc., Germantown, MD, USA). In accordance with the International Society of Biomechanics recommendations, local coordinate systems were constructed using the digitized anatomical landmarks. Motions of the clavicle, scapula, and humerus were described using Cardan and Euler angles.[18] The sternoclavicular joint motion describes motion of the clavicle relative to the thorax as posterior/anterior rotation, elevation/depression, and protraction/retraction (Fig. 2). Scapulothoracic joint motion describes motion of the scapula relative to the thorax as posterior/anterior tilt, lateral/medial rotation, and protraction/retraction (Fig. 3). Acromioclavicular joint motion describes motion of the scapula relative to the clavicle in a similar fashion as in ST joint motions, but this time relative to the clavicle. The entire RoM hereby was analyzed and not restricted to activities of daily living RoM. All kinematic waveforms were time-normalized by having the whole movement described with 101 data points ranging from 0% (rest position) to 50% (maximal end-RoM) to 100% (end position). Trials with artifacts were excluded, retaining a minimum of 3 good quality trials for each movement (4.3/6 movements withheld). Descriptive statistics (mean and standard error) of the variables were analyzed. Data analysis was performed by an independent blinded researcher (T.P.).

Results

In Table I, the mean rest positions at the start of the movement are given.

In the next paragraphs, the time-normalized graphs of the entire joint motions (start position - end RoM - end position) are shown. For each joint, the 3 different motions are shown in a separate graph for each axis. For clarity, the differences in motions will be described only from the start position until the end-RoM corresponding to the first 50% of the graphs.

Table I
Average rotation angles and standard deviations in the rest position of protraction, retraction, and shrug.

	Rest position	Standard deviation
Sternoclavicular joint		
Anterior rotation	−9°	±8°
Elevation	−4°	±5°
Retraction	−32°	±5°
Scapulothoracic joint		
Anterior tilting	−9°	±4°
Lateral rotation	1°	±5°
Protraction	33°	±6°
Acromioclavicular joint		
Anterior tilting	0°	±8°
Lateral rotation	−6°	±9°
Protraction	65°	±5°

Sternoclavicular joint

In Figure 4, *A*, it was demonstrated that shrug and retraction caused a posterior rotation of the clavicle compared to the thorax of 5° (−9° to −4, standard deviation [SD] 6°) and 3° (−10 to −7°, SD 2°), respectively, while protraction caused an anterior clavicular rotation of 3° (−10 to −13, SD 2°). In Figure 4, *B*, a very large elevation of 25° (−5 to −30, SD 5°) was demonstrated during shrug movement, while during protraction and retraction, the elevation of the clavicle was minimal. In Figure 4, *C*, it was demonstrated that while the clavicle moved 9° (−32° to −41°, SD 2°) further in retraction during the retraction movement itself, shrug movement caused a much larger retraction of 17° (−33° to −50°, SD 5°). During protraction movement, the clavicle showed a gradual protraction motion of 10° (−32 to −22°, SD 2°) of the clavicle compared to the thorax.

Scapulothoracic joint

In Figure 5, *A*, it was demonstrated that protraction and retraction have limited influence on the tilting position of the scapula compared to the thorax. The shrug movement showed 2 separate parts: during the first half of the movement, the scapula lost 1° (−8° to −7°, SD 1°) of anterior tilt, in the second half, anterior tilt increased about 4° (−7° to −11°, SD 2°). In Figure 5, *B*, a large lateral rotation of 26° (0° to −26°, SD 4°) of the scapula was seen during shrug movement. Retraction had a much more limited lateral rotation of about 4° (2° to −2°, SD 3°). In contrast, protraction showed a slight medial rotation of 1° (2°-3°, SD 1°). In Figure 5, *C*, protraction movement caused an increase of 7° (33°-40°, SD 2°) in the protraction position of the scapula. Shrug movement and retraction demonstrated almost a similar decrease in the protraction position of 9° (33°-24°, SD 2°) and 6° (32°-26°, SD 5°), respectively.

Acromioclavicular joint

In this paragraph, the relative motion of the scapula compared to the clavicle was described. In Figure 6, *A*, it was demonstrated that a very large increase in relative posterior tilt was seen during the shrug, increasing posterior tilting of the scapula compared to the clavicle with 23° (0°-23°, SD 6°). A smaller increase in posterior tilting of 4° (−1° to 3°, SD 3°) was demonstrated during protraction, while retraction showed only negligible changes. In Figure 6, *B*,

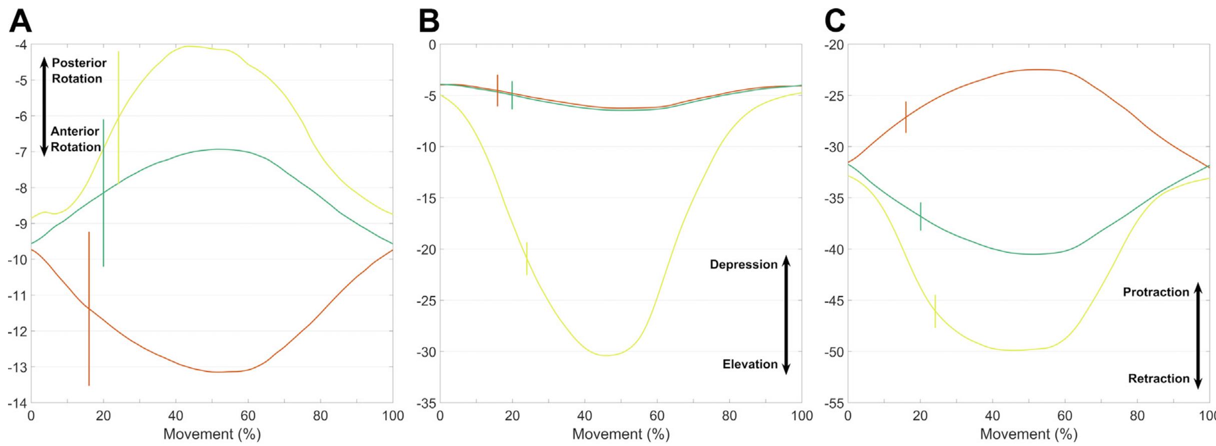

Figure 4 Time normalized graphs showing the mean kinematic angles in three axes (**A-C**) of rotation in the sternoclavicular joint during protraction (orange), retraction (green), and shrug (yellow); Double arrow indicates direction of motion. Vertical lines indicate standard errors.

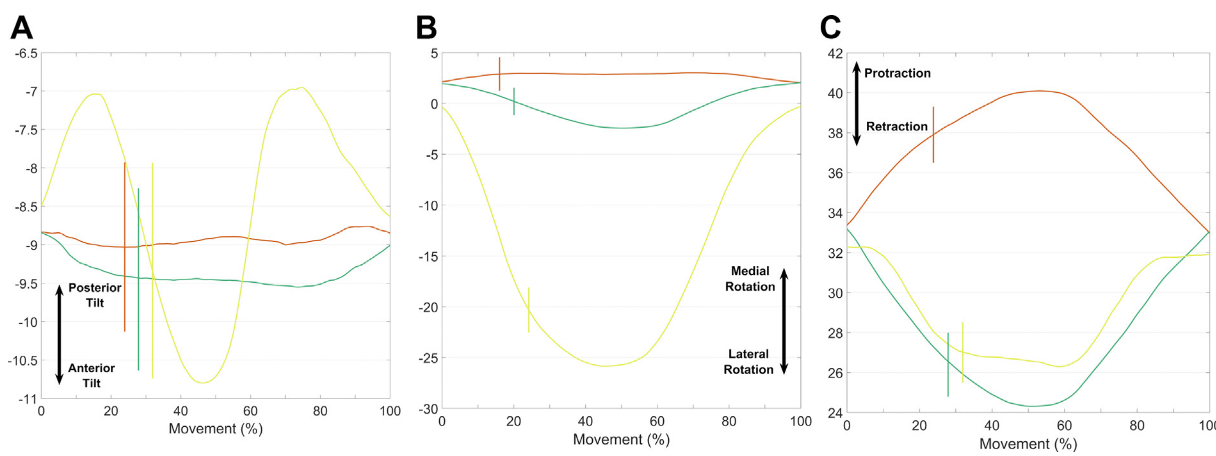

Figure 5 Time normalized graphs showing the mean kinematic angles in three axes (**A-C**) of rotation in the scapulothoracic joint during protraction (orange), retraction (green), and shrug (yellow); Double arrow indicates direction of motion. Vertical lines indicate standard errors.

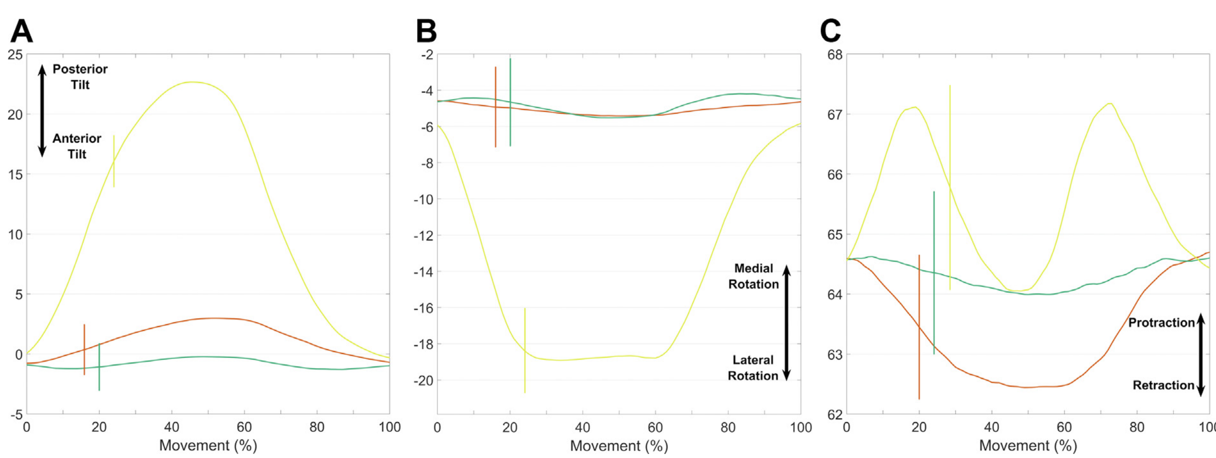

Figure 6 Time normalized graphs showing the mean kinematic angles in three axes (**A-C**) of rotation in the acromioclavicular joint during protraction (orange), retraction (green), and shrug (yellow); Double arrow indicates direction of motion. Vertical lines indicate standard errors.

shrug movement caused an increase in relative lateral rotation of 13° (−6 to −19°, SD 4°) with rotation occurring mainly during the first part of the movement and then remaining stable until the end of the RoM. Protraction and retraction again only induced negligible changes in the rotational position. During the shrug movement in Figure 6, C, an initial increase of 2° (65°-67°, SD 3°) of

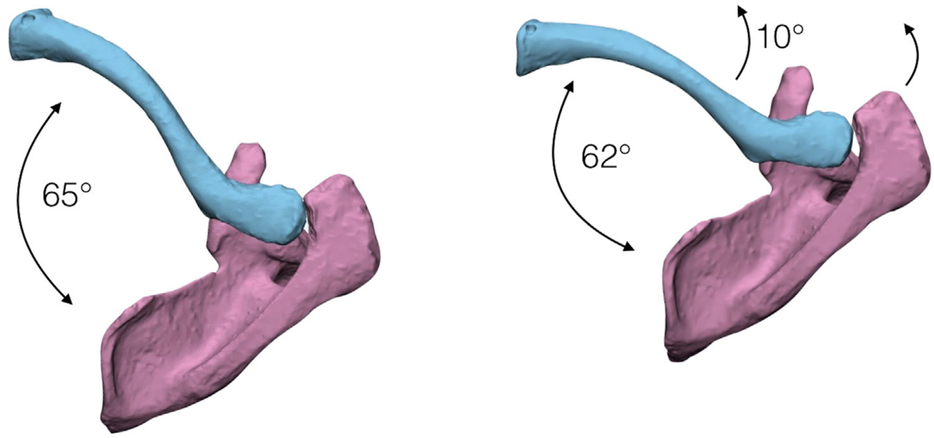

Figure 7 Illustration of the relative retraction in the acromioclavicular joint during protraction when the scapula is compared to the clavicle, which can be explained by the larger increase in protraction position of the clavicle compared to the thorax than the increase in protraction position of the scapula compared to the thorax.

protraction was observed, followed by a decrease of 3° (67°-64°, SD 2°). Paradoxically, the protraction movement decreased the relative protraction position with 3° (65°-62°, SD 2°). Retraction changed little to the protraction position of the scapula.

Discussion

In this descriptive laboratory study, a kinematic analysis was performed to illustrate normative values for the sternoclavicular, scapulothoracic, and acromioclavicular joint motions during 3 scapulothoracic movements.

In the sternoclavicular joint, it was demonstrated that scapulothoracic movements cause slight rotations of the clavicle compared to the thorax (Fig. 4, *A*). This confirmed the findings of Inman et al, who postulated in 1944 that during so called protrusion and retraction of the shoulders, only limited rotation of the clavicle occurred.[4,5] They found that this rotation occurred mostly in the SC joint, rather than in the AC joint. During coronal plane and sagittal plane elevation they noted a much larger rotation. This was confirmed in more recent studies by Oki et al and Ludewig et al.[10,14] Hereby, Oki et al demonstrated a posterior clavicular rotation of 18° and 15°, respectively, while Ludewig et al even had a higher average posterior clavicular rotation of 31°. The latter study demonstrated higher values because they measured until the end RoM, while Oki et al only measured joint motions until elevations of maximal 120°.[10,14]

Second, the shrug resulted in a very large increase of 25° of elevation of the clavicle (Fig. 4, *B*). This increase in elevation this time surpassed the measured values by Oki et al or Ludewig et al during coronal plane, sagittal plane, or scapular plane elevation with a maximal increase of only 18°.[10,14] Although this was already postulated by Codman, this kinematic evaluation confirmed this concept.[2] When the strut function of the clavicle is disturbed by pathological situations, inevitably the shrug movement could be severely affected as well.

Furthermore, it was demonstrated that the shrug movement induced a larger increase in retraction of the clavicle compared to the retraction movement itself. The latter is of course limited by the thorax, while the elevation of the clavicle and lateral rotation of the scapula during shrug creates room toward posterior allowing retraction to occur.

When we look at the scapulothoracic joint, indeed a lateral rotation (26°) of the scapula compared to the thorax was seen during shrug movement (Fig. 4, *B*). This is a smaller rotation than the existing values for coronal plane and sagittal plane elevation measured by Oki et al and Ludewig et al.[10,14] Oki et al found approximately 37° lateral rotation (described as upward rotation) during coronal plane elevation and approximately 30° of lateral rotation during sagittal plane elevation, while Ludewig et al reported an average of 39° for sagittal, coronal, and scapular plane elevation. When the shrug movement was investigated more closely in the other planes, it was noted that after an initial small loss of anterior tilt, an increase in anterior tilt of the scapula compared to the thorax occurred (Fig. 4, *A*), which is in contrast with the posterior tilting of the scapula during humerothoracic movements described by Oki et al and Ludewig et al.[10,14] Also, together with the smaller posterior rotation of the clavicula in the SC joint (Fig. 3, *A*), it can be concluded that the shrug movement induced clearly a different pattern compared to humerothoracic movements in which the arm is moved as well.

Second, it was demonstrated that protraction movement induced a small medial rotation of the scapula. Lunden et al also found a medial (downward) rotation of the scapula when examining push-up and push-up plus exercises. In their study, the additional protraction during the push-up plus induced also an average of almost 1° medial (downward) rotation.[11] It has to be noted that their protraction was performed in a push up position with the arm in 90° sagittal plane elevation, while we performed protraction with the arm next to the body.

Furthermore, protraction movement logically caused an increase in the protraction position of the scapula to a similar extent as the protraction of the clavicle, while retraction and shrug movement induced an increase toward retraction. This retraction movement caused a larger increase in the retraction position of the scapula in the ST joint compared to the increase in the retraction position of the clavicle in the SC joint; while in contrast, the shrug movement induced a larger increase in retraction of the clavicle in the SC joint than the increase in retraction position of the scapula in the ST joint.

Finally, in the acromioclavicular joint, the relative motions of the scapula relative to the clavicle were described. Because of this different reference frame, a comparison with the clavicle instead of the thorax as in SC and ST joint motions, the results should be interpreted differently as well.

An easy to understand example is the relative protraction position of the scapula compared to the thorax during the protraction movement (Fig. 7). While the clavicle moves 10° toward protraction compared to the thorax, the scapula only moves 7° toward protraction compared to the thorax. During this movement, the scapula has to slide around the thorax, while the clavicle at the same time acts as a strut for the scapula. This results in a relative retraction of the scapula compared to the clavicle in the AC joint itself, which might be counterintuitive when interpreting the protraction movement.

A slightly more difficult example is the large posterior tilt (23°) of the scapula compared to the clavicle during shrug, which can be explained by the large elevation of the clavicle (25°) compared to the thorax during shrug subtracted by a slight increase of about 3° of tilt of the scapula compared to the thorax. Ludewig et al found a comparable posterior tilting of 17° during sagittal plane elevation and an increase of 20° in posterior tilting during coronal plane elevation in the AC joint.[10]

The coupling of joint motions between the SC, ST, and AC joints was already investigated by Teece et al and Lawrence et al during humerothoracic elevation. In their experiment, Teece et al measured an angle of 68° between the clavicle and the scapula, while Lawrence et al used an angle of 60° to perform further calculations about the proportional contributions of joint motions.[7,17]

The results of this kinematic study suggest that scapulothoracic movements might be underestimated in its value when investigating kinematics of normal or pathologic situations in the shoulder girdle. For example, the shrug movement with a very large clavicle elevation could provide valuable information in kinematic analyses after clavicular fractures. Horizontal stability in a Rockwood V AC injury could be easier to evaluate during isolated scapulothoracic movement compared to complex coupled humerothoracic movements. On the other hand, the restoration of the rotational aspect of the clavicle after the repair of a Rockwood V AC injury might better be evaluated during humerothoracic movements such as coronal plane elevation. Therefore, both scapulothoracic and humerothoracic movements could be complementary in the analysis to provide a complete image of different types of lesions.

This study has different limitations. First of all, it was performed on cadaveric specimens, which had an average age of 85. At that age, the presence of some degenerative changes in the shoulder girdle is inevitable and might have influenced the results. Also, the motions were performed passively. The effect of muscle contractions attached to the clavicle and scapula could alter the results of joint motions in intact shoulders, and potentially even more in injured shoulders. Nonetheless, Teece et al demonstrated that passive shoulder joint motions of upright sitting whole cadaveric specimens were comparable to the RoM to those of active trials in human subjects.[17] Furthermore, the movements were performed until the end RoM, but the force that was applied was not objectively measured and therefore any variability cannot be excluded. Finally, only rotational and no translational joint motions were analyzed.

Conclusion

This study provided normative values of scapulothoracic movements in the shoulder girdle. These values can be used when investigating scapulothoracic kinematics during normal and pathologic situations.

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