Abduction of the Arm in the Scapular Plane: Scapular and Glenohumeral Movements

A Roentgenographic Study*

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Abduction of the arm at the shoulder involves a complex variety of movements which have been the subject of numerous analyses and discussions. There are, however, still divergences of opinion on several facets of the functional interrelationships of the participating muscles and joints.

The most comprehensive recent investigation of the shoulder region was made by Inman, Saunders, and Abbott. The movement of abduction in that study was performed in the coronal plane, but many workers [6,9] have stressed the advantages of using the scapular plane when discussing shoulder movements.

In the present study the relationships between scapular and glenohumeral movements during abduction of the arm in the scapular plane have been examined by the analysis of roentgenograms and these results have been compared primarily with those obtained by Inman, Saunders, and Abbott in the coronal plane.

Materials and Methods

Roentgenograms were made of the right shoulder region of sixty-one male medical students from the University of Sydney with their arms in five positions of abduction in the scapular plane. The ages of these subjects ranged from seventeen to twenty-four years. Records were kept of height, weight, certain relevant anthropometric measurements, left or right handedness, and history of previous roentgenography or of right shoulder injury.

For practical purposes of study, a mean position had to be assumed for the scapular plane. Following Steindler, the scapula was taken to lie at 30 degrees to the coronal plane; the slight downward inclination of the scapula was disregarded. It was appreciated, however, that these were approximations and that, in addition to individual variations, during abduction of the arm there were changes in angulation of the scapula to both the coronal and the transverse planes in conformity with the curvature of the thoracic wall.

The five positions used for the study of abduction in the scapular plane were: 0 degrees, 45 degrees, 90 degrees, 135 degrees, and maximum abduction. Each subject was carefully positioned with his right shoulder against the roentgenographic plate and his feet at right angles to parallel lines drawn on a baseboard at 30 degrees to the plane of the plate (Fig. 1). With the elbow extended and the palm facing forward, the angle of the right arm was adjusted in a plane parallel to the roentgenographic plate by the use of a protractor with movable plastic arms, to one of which a spirit level was attached (Fig. 2). In order to prevent any tendency of the individual to lean to the left side, the left arm was raised in line with the body to an angle similar to that of the right arm.

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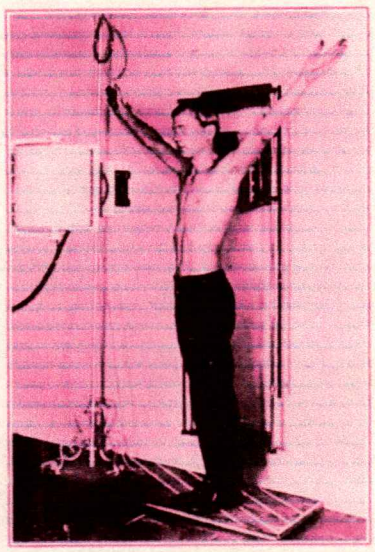

FIG. 1

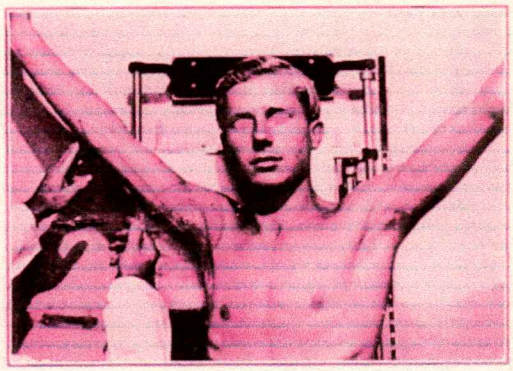

FIG. 2

Fig. 1: Subject positioned for roentgenography (135 degrees of abduction).
Fig. 2: Protractor for setting arm angle.

The x-ray machine employed was a Stanford 90–30 portable unit, with an added 2 mm. aluminum filter and a Universal Light Beam Diaphragm. A stationary grid was used. The film was Kodak Royal Blue, fourteen inches by eleven inches. The basic roentgenographic settings were 70 kv and 30 ma and the exposure time was varied from 3 8 to 3 4 second. The exposure time for each individual was determined by the maximum anteroposterior measurement of the shoulder region as measured with an anthropometer.

For the analysis of humeral and scapular movement, lines were drawn on each roentgenogram to represent the long axis of the shaft of the humerus and the orientation of the glenoid cavity of the scapula. The line for the humerus was drawn as nearly parallel as possible to the medial border of the diaphysis as seen on each roentgenogram so that the line approximately bisected the shaft. With regard to the glenoid cavity, a line was drawn which passed through the most superior and the most inferior points of the concave articular surface as seen on the roentgenograms (Figs. 3-A through 3-E).

The glenoid cavity line was chosen to represent the orientation of the scapula after several alternatives had been tried. The medial border of the scapula was not clearly visible on the majority of the roentgenograms and, as a rule, only certain landmarks of the spine of the scapula could be clearly discerned. One of the most constant of the latter took the form of a St. Andrew's cross formed by two intersecting lines (Figs. 3-B, 3-C, and 3-D). The line which starts superiorly on the medial side represents the upper border of the attachment of the spine to the body of the scapula, and it terminates laterally in the region of the root of the coracoid process. The line which starts inferiorly on the medial side represents an osseous ridge running along the crest of the scapular spine and demarcates the lower limit of the attachment of the trapezius muscle. These features of the scapular spine were not always clearly visible in the roentgenograms and hence could not be used to define the changing positions of the scapula.

The humeral and scapular lines drawn on the roentgenograms were prolonged to the appropriate edges of the film, which were taken to represent the vertical and horizontal axes. The angles recorded for each individual in each of the five positions were: the angle of the glenoid-cavity axis to the vertical—the scapular angle (*S*),

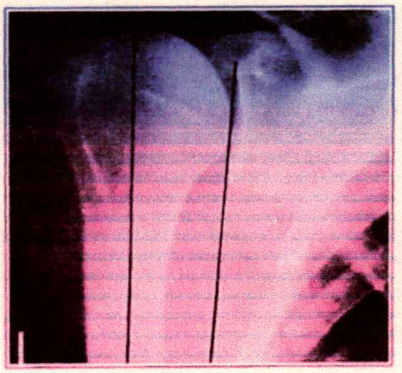

FIG. 3-A

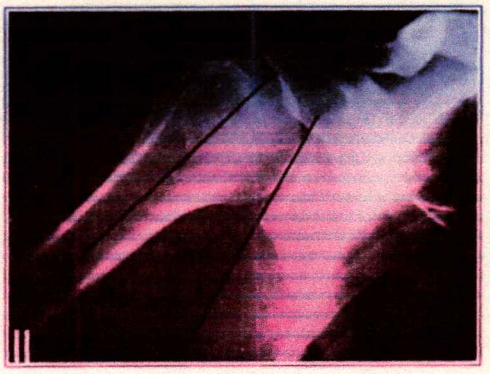

FIG. 3-B

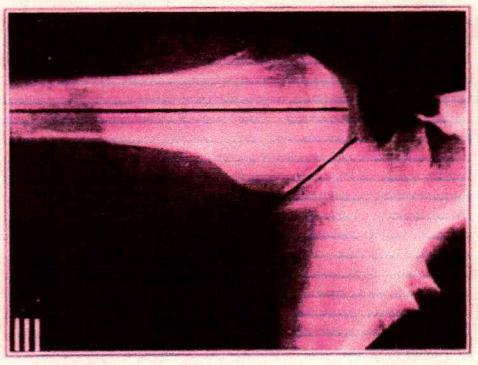

FIG. 3-C

FIG. 3-D

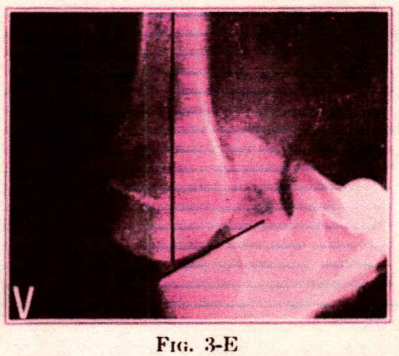

FIG. 3-E

Figs. 3-A through 3-E: Roentgenograms of the shoulder region with lines drawn to represent the long axis of the humerus and glenoid cavity of the scapula in positions I, II, III, IV, and V.

and the angle of the humerus to the vertical—the angle of the arm (*A*). The glenohumeral angle (*GH*) for each position was obtained by subtracting the scapular angle (*S*) from the angle of the arm (*A*).

Analysis

Of the sixty-one subjects studied, nine were eliminated because a full series of five technically satisfactory roentgenograms was not obtained. For the remaining fifty-two, the mean values and standard deviations of the angles of the arm, of the scapular angles, and of the glenohumeral angles were obtained as listed in Table

TABLE I

MEAN VALUES AND STANDARD DEVIATIONS (IN DEGREES) OF THE ARM (*A*), SCAPULA (*S*), AND THE GLENOHUMERAL ANGLES (*GH*) IN THE FIVE POSITIONS STUDIED

Positions	Angles					
	A		S		GH	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
I	−0.83	4.35	−5.29	6.77	4.46	6.95
II	44.29	3.81	13.27	8.49	31.02	8.87
III	86.79	2.51	31.13	8.77	55.65	8.71
IV	127.90	4.08	49.38	5.78	78.52	6.68
V	167.17	7.57	59.67	4.67	107.50	9.13

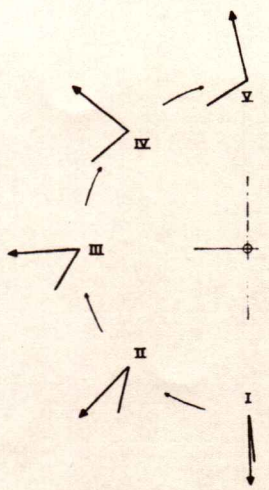

FIG. 4

Diagrammatic representation of the mean angles of the scapula (short line) and humerus (long line with arrow head) in the five positions studied.

I for each of the five positions studied. The mean values are utilized in Figure 4 to illustrate the continuous movement of both the scapula and the humerus, and their changing relationships during abduction of the arm.

The relationship of glenohumeral angle to degree of abduction of the arm was next examined. A regression line for predicting glenohumeral angle (Y) from arm angle (X) was calculated by the method of least squares and found to be: $Y = 3.941 + 0.605\ X$. This line and the 95 per cent probability interval for the points are shown in Figure 5. The 95 per cent confidence limits for the regression line were also calculated. These limits for seven points are shown in Table II. It can be seen from this table that they lie very close to the regression line and only diverge slightly at either end.

TABLE II

95 PER CENT CONFIDENCE INTERVAL FOR THE REGRESSION LINE: $Y = 3.941 + 0.605\ X$, AT SEVEN SELECTED POINTS

Points (*degrees*)	0	30	60	90	120	150	180
95% C. I.	±1.53	±1.17	±0.90	±0.82	±0.97	±1.28	±1.65

A test for linearity of the regression line [10] was performed and an F value of 2.09 was obtained with 3 degrees of freedom in the numerator and 255 degrees of

TABLE III

RELATIVE AMOUNTS OF MOVEMENT OF THE SCAPULA AND HUMERUS IN FOUR PHASES OF ABDUCTION

Interval	Ratio GH/A	Ratio GH/S
I–II	0.589	1.431
II–III	0.580	1.379
III–IV	0.556	1.253
IV–V	0.738	2.729

freedom in the denominator. (With these degrees of freedom: when $F = 2.08$, $P = 0.1$; when $F = 2.60$, $P = 0.05$). Using a 5 per cent level of acceptance as a basis, there appeared to be a linear relationship, since we may assume that the departure of the observed glenohumeral angles from the linear relationship was due to random error.

The ratios of glenohumeral to total arm movement (*GH/A*) and of glenohumeral to scapular movement (*GH/S*) for the four intervals between the five positions were also calculated (Table III). These ratios were derived from the sums of the individual changes of the glenohumeral angles divided by the sums of the individual arm angles and of the scapular angles during each phase. The GH/A ratio for phase IV–V can be seen to differ from the first three ratios which are very similar. This discrepancy is more obvious when one examines the GH/S ratios (Table III). Because of the linear relationship between A, S, and GH and the assumed linear relationship between GH and A, we can assume that GH and S are also linearly related.

The ratios of glenohumeral to total arm movement could also have been derived by taking the individual ratios for each phase for each subject and calculating the mean values for each phase, but this approach would not be strictly comparable with the method used for calculating the regression line. It might be noted in passing, however, that in the GH/S ratios derived in this manner, there is greater variability in the first three phases and that the fourth phase displays an even greater difference than by the other method (GH/S: I–II, 1.35; II–III, 1.64; III–IV, 0.97; IV–V, 3.51).

Discussion

In the past, abduction of the arm has been described in both the coronal plane and in the plane of the scapula, but the latter has been favored recently since it appears to be a less complex and more natural movement. The scapula, humerus, and the attachments of the principal humeroscapular muscles involved—and hence their most direct line of action—all lie in a single plane. Further, it is generally held that lateral rotation of the humerus is necessary for coronal abduction, but that for abduction in the scapular plane no appreciable rotation is required [2,6]. In addition, in surgical practice, it has been found most satisfactory to arthrodese the glenohumeral joint in approximately the scapular plane. Finally, from a purely practical point of view, using the scapular plane for analyzing abduction has the merit that there is comparatively little distortion of the angles being measured on the roentgenograms.

Table I summarizes the basic observations made on the roentgenograms in the present study. From an inspection of the mean values for the five positions of abduction of the arm (*A*), it can be seen that the angles achieved fall short of the angles aimed at in the first four positions. The discrepancy becomes progressively more marked as the degree of abduction increases, primarily due to the greater

muscle effort required to maintain more abducted positions. The fifth position represents the mean maximum angle of abduction reached. The mean figure is just over 167 degrees and the observed range of variation is 148 to 182 degrees. The individual values of maximum abduction are distributed as follows: $<150°$, 3.8%; 151° to 160°, 13.5%; 161° to 170°, 46.2%; 171° to 180°, 32.7%; $>180°$, 3.8%.

The various mean positions assumed by the glenoid cavity during abduction in the scapular plane are given by the angles S in Table I. It is of interest that, on the average, the glenoid cavity faces inferiorly a little over 5 degrees from the vertical in the first position, and the observed range varies from -22 to $+12$ degrees. Part of this slight downward facing of the glenoid cavity in the first position is accounted for by the fact that the arm was slightly adducted to an average of -0.83 degree, but it is apparent nevertheless that, in the anatomical position, the average glenoid cavity faces slightly downward. Basmajian and Bazant postulated a mechanism for preventing downward displacement of the vertical or adducted humerus. According to this hypothesis, the head of the humerus is held in place by the tension of the superior part of the capsule and contraction of the horizontally running muscles holding the head against the glenoid cavity which according to this concept must face at least slightly upward. Their electromyographic studies confirmed the presence of activity of the horizontally acting supraspinatus and also of the posterior fibers of the deltoid when the arm was vertical or adducted, but no activity was detected in the vertical fibers of the deltoid, biceps, and long head of the triceps. In view of the fact that in the present series the glenoid cavity faced slightly downward in 80.8 per cent of individuals in the first position, this theory requires reassessment.

For the whole series, the mean total scapular movement was 65 degrees and the mean total glenohumeral movement, 103 degrees. These figures fall within the ranges given by Davies and Davies, who stated that scapular rotation during abduction is 60 to 65 degrees and glenohumeral movement, 100 to 120 degrees.

The standard deviations of angle A for positions I through IV (Table I) indicate the amount of variation obtained in achieving each of these positions. The 90-degree position shows the least amount of variation. The standard deviation for position V indicates the variability in the maximum amount of abduction among the different individuals. The standard deviations for the angles S and GH include variation due both to differences in angle A achieved and to variation in the individual ratio of GH to S. Because of this, all the standard deviations of S and GH are greater than those of the equivalent A, with but one exception, the standard deviation of S in position V. This lower figure might in part be accounted for by the fact that, during the last phase of abduction, there is a decrease in the relative amount of scapular movement (Table III), but it would seem more likely that the decreased standard deviation of S here indicates that the final position of the scapula is relatively more constant than the final glenohumeral angle.

There has been considerable divergence of opinion in the past on the relative roles of scapular rotation and glenohumeral movement in abduction of the arm [3,4]. Inman, Saunders, and Abbott confirmed the findings of Lockhart stating that, during coronal abduction, scapular rotation and increase in the glenohumeral angle occur together throughout most of the movement. More precisely, they concluded that between 30 degrees and 170 degrees "a ratio of two of humeral to one of scapular motion obtains." In the first 30 degrees of abduction, however, they found great variability, with the scapula seeking stability by moving medially, laterally, both or neither, in what they termed the *setting phase*.

The regression line obtained in the present study for predicting angle GH from total arm movement (Fig. 5) implies that on the average over the full range of ab-

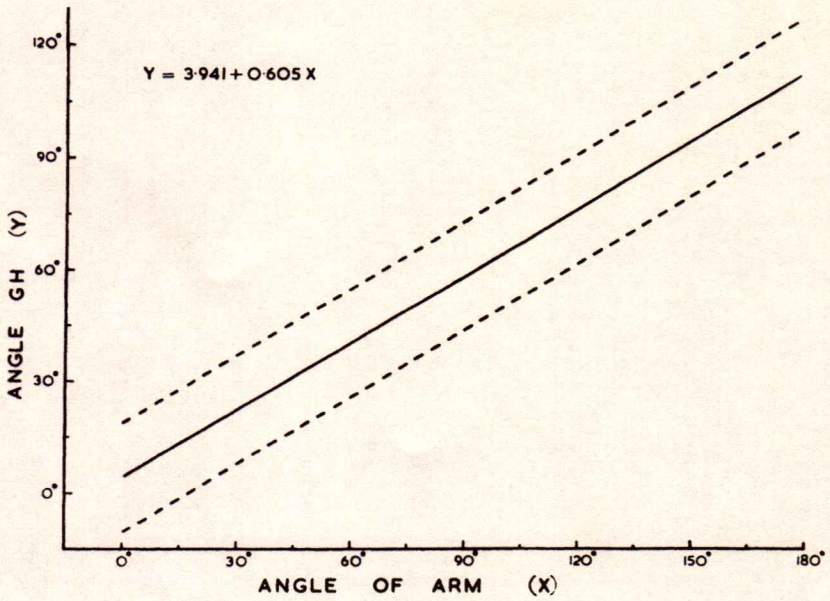

FIG. 5

Regression line for predicting the glenohumeral angle (*GH*) from the angle of the arm (*A*) during abduction in the scapular plane. Dotted lines represent the 95 per cent probability interval for the observations.

duction in the scapular plane, of every 1 degree of abduction of the arm the glenohumeral angle contributes 0.605 degree, or alternatively, for every 2 degrees of scapular rotation there are 3 degrees of glenohumeral movement. The linearity of this relationship reached the 5 per cent level of significance, but some variation was found when the four phases were analyzed separately (Table III). The ratio of GH/S for the first phase was similar to that in the succeeding two phases but, for the final phase, it was considerably higher.

The difference between the over-all ratio obtained in the present study and that of Inman, Saunders, and Abbott could be due to the different planes in which the movement was performed. However, the 95 per cent probability interval (which amounts to ±15 degrees) found in the present study (Fig. 5) indicates a wide range of individual variation and is similar to the probability interval found in the earlier study. At least some of the difference between the ratios obtained in the two studies may be accounted for by this variation.

Summary

1. The relative amounts of scapular (*S*) and glenohumeral (*GH*) movements have been investigated roentgenographically, using sixty-one male subjects each with the arm in five positions of abduction in the scapular plane.

2. The five positions of abduction studied yielded a number of interesting points. Of special interest is the fact that, in the rest position, the glenoid cavity of the scapula faces somewhat inferiorly in over 80 per cent of the individuals, the mean downward inclination for the series being slightly over 5 degrees.

3. The mean total scapular rotation was 65 degrees and the mean total glenohumeral movement, 103 degrees. The percentages of subjects reaching different maximum amounts of abduction have been recorded.

4. A regression line for predicting glenohumeral angle (*Y*) from arm angle (*X*) was calculated (Y = 3.941 + 0.605 X), which indicates that, during abduction in

the scapular plane, for every 2 degrees of scapular rotation, there are, on the average, 3 degrees of glenohumeral movement.

5. The linearity of this relationship could not be rejected at the 5 per cent level of acceptance, and this implies that the ratio is constant for the whole movement. However, when the full movement was analyzed in four phases, a higher GH/S ratio was found in the final phase, indicating a relative increase of glenohumeral motion as the final stage of abduction is reached.

6. The 95 per cent probability interval calculated for the observations (± 15 degrees) indicates a considerable amount of individual variation in the movements.

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