NOW AND THEN

Ranges of movement at the shoulder complex using an electromagnetic movement sensor

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Abstract

There are few published data on the ranges of available motion at the shoulder and no clinical technique for the assessment of three dimensional movement. An electromagnetic movement sensor (Isotrak), which makes three dimensional measurements of shoulder movement and measures the ranges of flexion, extension, abduction in the neutral position, abduction preceded by external rotation, and internal rotation achieved by placing the hand as far up the back as possible, was used to study 16 normal subjects.

Intraobserver repeatability was good, and a study of five subjects by two observers showed no significant difference between single measurements made by each. The measured ranges were in broad agreement with published data, though they tended to be smaller. This was attributed to either the bulk of the mounting for the movement sensor or to the immobilisation of the elbow and hence the biceps muscle. Women had greater ranges, except for externally rotated abduction.

Despite the common occurrence of arthritic and other disabling conditions of the shoulder and the consequent need to evaluate treatment there are few published data on the ranges of movement of the joint complex. Probably the most commonly quoted values are those published by the American Academy of Orthopaedic Surgeons,[1] which represent averages from earlier published work. Boone and Azen[2] used traditional goniometers to measure horizontal and forward flexion and extension, abduction, and humeral rotation, and Clarke and colleagues[3] used hydrogoniometers to measure the ranges of

passive abduction and rotation. Allander and colleagues also measured ranges of rotation using a large traditional goniometer.[4] In the 1950s Salter and Darcus described a specially designed fixture to measure humeral rotation.[5] Table 1 summarises the published data.

Although the traditional protractor goniometer is convenient in clinical use, the difficulties of initial alignment with the limb and the trunk can lead to appreciable inaccuracies. Boone and colleagues[6] made a detailed study of the repeatability of goniometer readings and concluded that provided the same observer took all the measurements of the same subject changes of 4 degrees could be detected reliably, though it seems likely that these findings relate to highly trained observers. In their thorough study of the use of hydrogoniometers Clarke et al found standard deviations of 13·3, 7·7, and 7·5 degrees for measurements of the passive ranges of total humeral rotation, external rotation, and abduction respectively based on eight successive readings taken over four days.[3]

Apart from the problems of repeatability, traditional goniometers are also limited by the fact that they can only make planar measurements of motion which is almost always (in the case of the shoulder) three dimensional and in which small out of plane movements may have a considerable effect on the measured range. Our report describes work using an electromagnetic movement sensor to measure three dimensional shoulder motion; the method of use of this system has been described previously.[7] This paper reports the measurement of active flexion, extension, abduction, and internal rotation of 16 normal subjects and compares the results of two independent observers who made measurements on five of these subjects.

Table 1 Ranges of motion at the shoulder: published data

Authors	Movement	Active/passive	Range (deg)
Allander et al (1974)[4]	Humeral rotation	P	111–125
Boone and Azen (1979)[2]	Horizontal flexion	A	140·7
	Horizontal extension	A	45·4
	Abduction	A	184·0
	Forward flexion	A	166·7
	Backward extension	A	62·3
	Internal rotation	A	68·8
	External rotation	A	103·7
Boone et al (1978)[6]	Humeral rotation	A	96·9–104·7
Clarke et al (1974)[3]	Humeral rotation	P	158–159·7
	Abduction	P	98·9–101·8
Salter and Darcus (1953)[5]	Humeral rotation	A	134–141
AAOS* (average)[1]	Horizontal flexion	A	135
	Abduction	A	170
	Forward flexion	A	158
	Backward extension	A	53
	Internal rotation	A	70
	External rotation	A	90

*AAOS=American Academy of Orthopaedic Surgeons.

Methods

The Isotrak system (Polhemus Navigation Systems, USA) for the measurement of shoulder movement operates by attachment of an electromagnetic source to the upper arm using a moulded thermoplastic splint, which encompasses the elbow in order to locate the humerus, and a small sensor attached over the sternum using adhesive tape (fig 1). Four different test manoeuvres were measured as follows: (a) flexion/extension in the saggital plane; (b) abduction in the frontal plane, forearm pointing forward (abduction (N)); (c) abduction in the frontal plane, preceded by external rotation (abduction (ER)); (d) abduction and internal rotation achieved by the subject placing the arm as high up the back as possible.
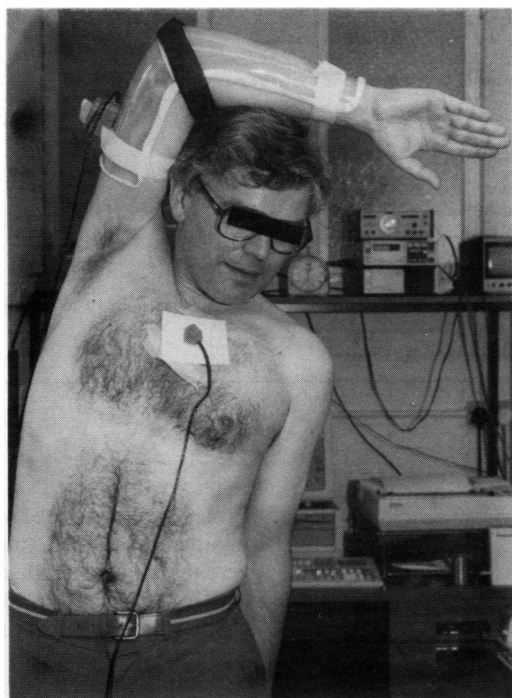
Figure 1 The Isotrak system.

Each test movement was started from the neutral position, which was carefully checked by the observer.

Specialist software has been written both to calculate the angles of movement and the range of motion achieved in each manoeuvre as follows: (*a*) flexion, extension, range=flexion + extension; (*b*) abduction (N); (*c*) abduction (ER); (*d*) internal rotation.

Measurements of all four manoeuvres were carried out on 16 test subjects (11 female/five male) by either one or two (NF, MH) of the authors. Measurements on five of the subjects were made up to five consecutive times to study intraobserver variation; all other measurements were made once' only. The observers were unaware of the data at the time of measurement as the calculation of ranges of motion took place after each set of manoeuvres. Table 2 gives

Table 2 Details of 16 test subjects: 11 female, mean age 39·2 (range 21–77); five male, mean age 52 (range 26–69)

Measurement	Subjects measured by:		
	Observer 1	Observer 2	Total No
Repeated observations	4	1	5
Single observations	15	6	16

details of the subjects and measurements. The subjects were all staff or orthopaedic patients with disorders unrelated to the upper limb in the hospital in which the study was carried out; numbers were limited by the availability of volunteers.

Results

VARIATION IN CONSECUTIVE MEASUREMENTS

Table 3 shows the results of the consecutive tests, together with the analysis of variance. In all cases the F statistic indicated significant differences between the mean measurements of the five test subjects ($p<0·05$).

INTEROBSERVER VARIATION

Figure 2 shows graphically the results obtained from single measurements of five subjects by the two observers; table 4 shows the differences
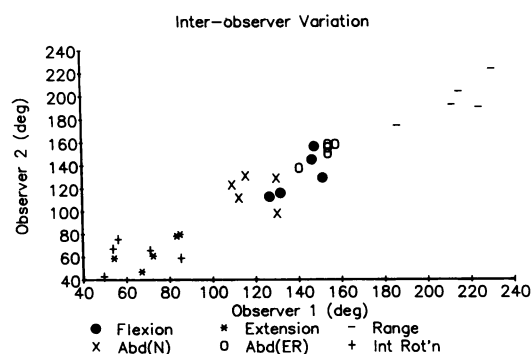

Figure 2 Correlation between measurements of the five subjects by two observers. Abd (N)=abduction in the frontal plane, forearm pointing forward; Abd (ER)=abduction in the frontal plane, preceded by external rotation.

Table 3 Means and standard deviations of repeated measurements of shoulder ranges

	Case No					F statistic
	1	2	3	4	5	
Flexion	56·67	100·83	80·80	58·00	71·23	22·37
SD	(2·63)	(11·82)	(1·76)	(3·52)	(11·02)	
n	3	3	3	5	3	
Extension	139·80	144·20	122·07	114·62	147·50	13·45
SD	(6·88)	(4·69)	(9·56)	(6·81)	(9·91)	
n	3	3	3	5	3	
Abduction (N)	113·2	126·07	134·20	103·9	127·3	7·65
SD	(10·80)	(6·15)	(1·65)	(5·03)	(15·53)	
n	3	3	3	5	3	
Abduction (ER)	149·37	175·55	152·87	121·58	178·10	141·1
SD	(4·79)	(0·92)	(5·72)	(2·87)	(1·67)	
n	3	2	3	5	3	
Internal rotation	62·45	52·00	86·60	39·38	74·77	37·45
SD	(0·35)	(1·70)	(5·23)	(2·69)	(10·00)	
n	2	2	2	5	3	

Table 4 Differences (observer 1–observer 2), mean differences, 95 per cent confidence intervals, and mean absolute differences between measurements by two observers

Case No	Flexion	Extension	Range	Abd (N)	Abd (ER)	Internal rotation
6	5·07	13·82	18·89	−0·93	4·39	−6·53
7	11·59	21·95	33·54	−0·88	−2·70	13·36
8	−4·51	15·89	11·38	−32·09	0·98	−26·44
9	19·97	−9·23	10·75	15·33	−3·50	−5·57
3	−6·14	−0·35	−6·49	13·81	1·67	19·27
Mean	5·20	8·42	13·61	−0·95	0·17	−1·18
SD	10·98	12·81	14·51	19·06	3·26	18·14
95% confidence intervals	15·02 to −4·62	19·88 to −3·04	26·59 to 0·63	16·10 to −18·00	6·18 to 0·34	34·36 to 1·92
Mean absolute differences	9·46	12·25	16·21	12·61	2·65	14·23
SD	6·51	8·07	10·67	12·87	1·37	8·80

Table 5 Mean (SD) ranges of motion for the group of 16 normal subjects

Movement	This study		Previous workers	
	M (n=5)	F (n=11)		
Flexion	127·6 (18·4)	140·7 (15·5)	166·7 158	(Boone and Azen)[2] (AAOS)[1]
Extension	63·9 (13·5)	70·5 (15·9)	62·3 53	(Boone and Azen)[2] (AAOS)[1]
Range*	191·5 (24·5)	211·2 (18·92)	229 211	(Boone and Azen)[2] (AAOS)[1]
Abduction (N)	117·0 (25·2)	130·3 (11·6)	100·5	(Clarke et al)[3]
Abduction (ER)	168·5 (50·0)	160·8 (19·5)	184·0 170	(Boone and Azen)[2] (AAOS)[1]
Internal rotation	52·3 (19·6)	67·1 (16·3)	68·8 70	(Boone and Azen)[2] (AAOS)[1]

*Calculated as flexion+extension.

(observer 1–observer 2) between the measurements. There was no significant difference between the means of any of the measured ranges (p<0·05, paired t test). The 95 per cent confidence limits are shown immediately beneath the standard deviations. The mean absolute differences have also been presented to help evaluate the reliability of making the different measurements.
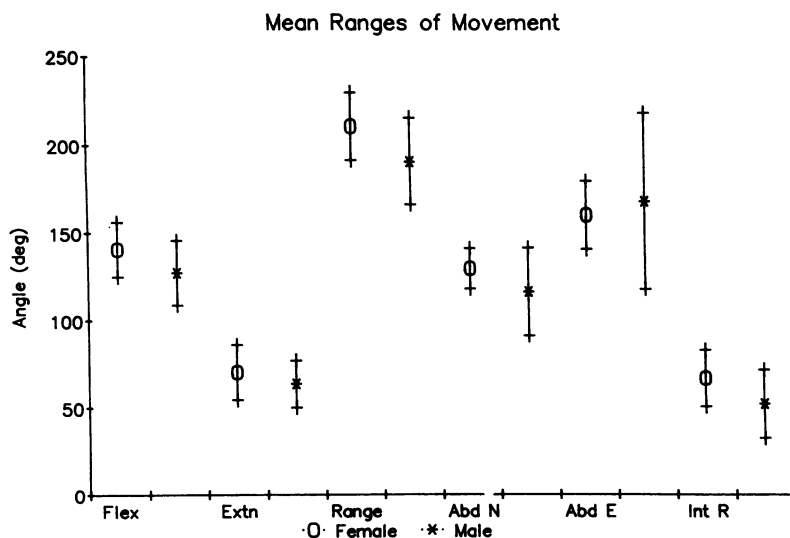
Mean Ranges of Movement

Figure 3 Mean ranges (standard deviation) of shoulder motion of male and female subjects.

SAMPLE VARIATION

Table 5 shows the mean ranges of motion obtained for all 16 subjects. All of these data were taken from single observations by observer 1 with the exception of the data on observer 1 which were, by necessity, made by observer 2. Figure 3 summarises the data graphically, showing the means (standard deviations) of the six measurements for male and female subjects.

Discussion

The technique presented here allows, for the first time, comprehensive assessment of active motion at the shoulder complex using a common reference starting position for all measurements. The interobserver and intra-observer studies showed that although one observer can obtain repeatable measurements there can, in some cases, be large interobserver differences. This finding is consistent with the work of Boone and colleagues[6] and is thought to represent differences of both the definition of starting positions and subject motivation. The F statistics, however, show that the technique was sufficiently reliable to detect differences between the subjects for all measurements. It is also interesting to note that, in general, the inter-observer differences are not consistent, that is to say observer 1 does not always achieve higher readings than observer 2. An exception to this is the measurement of the overall range of flexion/extension, where the definition of a starting point is irrelevant, for which observer 1 produces consistently higher readings. This supports the suggestion that for the other results it is variation of the initial zero which causes much of the unreliability. The most reliable measurements seem to be those of abduction (ER), though it is not clear why this should be so; the most unreliable are those of internal rotation, which may reflect slightly varying interpretations of the manoeuvre. Overall, these findings support the suggestion of Boone and colleagues[6] that sequential studies should be carried out by one observer.

Table 5 gives a comparison of the results obtained here and those of other studies. It is interesting to note that, with the exception of extension and abduction (N), all the ranges reported here are smaller than those from other studies. The relatively close agreement for the overall ranges of flexion/extension once again

suggests that differences in the initial zero point may be responsible. In addition to variations in the starting position, there may also be differences in the definition of anatomical planes resulting from the method of attachment of the sternum reference marker as well as a slight restriction of movement caused both by the bulk of the attachment and the immobilisation of the elbow. Although the ranges of abduction (ER) agree reasonably well with published data, those of abduction (N) are considerably smaller than many published values (see table 1). This is to be expected as movement in this position is limited by impingement. Measurements of internal rotation are not truly comparable as the published figures were obtained with the shoulder in forward flexion. The finding that women have greater ranges of movement than men is in general agreement with the results of Allander and colleagues.[4] There also seems to be a trend for ranges to decrease with age, but the number of subjects in this study was too small to allow statistical analysis.

Conclusions

It has been shown in this paper that comprehensive data on mobility of the shoulder complex may be obtained using Isotrak. Although the repeatability of sequential measurements has been found to be good, there are in some cases large discrepancies between the results from different observers, which can, to a certain extent, be attributed to variations in the starting position but are worthy of further study. These problems have already led to a modification of the Isotrak software requiring an alignment procedure to be performed before measuring the subject.

The mean measured ranges for the 16 subjects agree reasonably well with other published results and tend to be smaller. It is thought that this may be caused partly by immobilisation of the elbow and, in particular, the biceps muscle.

It is also possible that the bulk of the arm splint impeded movement. After investigation of these problems there is a need to examine the influence of age and sex on ranges of movement and to study differences between dominant and non-dominant shoulders.

All the data presented here are concerned with total movement of the shoulder complex and there has been no attempt to separate scapular and glenohumeral movements. Although direct measurement of scapular movement will not be possible with this system, analysis of the three dimensional rigid body motion of the humerus can be achieved. Techniques to do this are currently under development.

In conclusion, Isotrak has been shown to be a suitable tool for the measurement of shoulder movement. Although its use may be a little too time consuming for routine clinical use, it will be valuable for the study of treatment methods and joint replacement.

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