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PRECLINICAL STUDY

Three-dimensional scapulothoracic motion following treatment for breast cancer

Delva Shamley · Ragavan Srinaganathan · Reza Oskrochi · Ion Lascurain-Aguirrebeña · Elaine Sugden

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Abstract Varying levels of shoulder morbidity following treatment for breast cancer have been reported. Patients report pain, weakness, tightness and reduced functional capacity. Normal painfree motion of the arm and shoulder requires mobility in the scapulothoracic, glenohumeral, acromioclavicular and sternoclavicular joints. Under healthy conditions elevation of the arm is accompanied by scapula retraction, lateral rotation and posterior tilt. However, when scapulothoracic motion is disproportionate to glenohumeral motion, the potential exists for microtrauma and long term pain. A number of studies on women treated for breast cancer have shown limitations in glenohumeral range of movement and a recent report from our laboratory has shown decreased muscle activity in four key muscles acting on the scapula. However, no study has measured the effect of treatment on three-dimensional (3-D) scapulothoracic motion in relation to glenohumeral motion. 152 women treated for unilateral carcinoma of the breast were included in the study. All patients filled out the Shoulder Pain and Disability Index (SPADI). 3-D—kinematic data for the humerus and scapula was recorded during scaption on the affected and unaffected side. The association between kinematic data, SPADI and covariates was determined using random effects multiple regression techniques. All scapula kinematic parameters were significantly altered on the side of the carcinoma in breast cancer survivors. Both reported levels of pain and dysfunction were associated with altered kinematics. High levels of pain and disability were reported for up to 6 years post surgery. Patients with the left side affected reported higher levels of pain and demonstrated more significant scapulathoracic dysfunction independent of dominance. Altered movement patterns were different for left versus right side affected. Left side affected patients need to be considered as a group of patients at risk of experiencing higher levels of pain and showing greater shoulder dysfunction. Whether cause or effect, pain reports are accompanied by 3-dimensional scapula dysfunction which mimics that of many other shoulder conditions.

Keywords Kinematics · Shoulder · Pain lateralisation

D. Shamley (✉)
Centre for Postgraduate Medical Research and Education, Bournemouth University, Rm 206, Royal London House, Christchurch Rd, Bournemouth BH1 3LT, Dorset, UK
e-mail: dshamley@bournemouth.ac.uk

R. Srinaganathan · I. Lascurain-Aguirrebeña
Department of Physiotherapy, Oxford Brookes University, Oxford, UK

R. Oskrochi
Department of Mathematical Sciences, Oxford Brookes University, Oxford, UK

E. Sugden
Department of Oncology, Churchill Hospital, Oxford, UK

Introduction

The potential for shoulder morbidity following treatment for breast cancer is an established fact [1–6]. Risk factors for acute postoperative pain include anxiety [7] and for chronic postoperative pain more invasive surgery, radiotherapy and acute post-operative pain [8, 9]. Patient reports of arm morbidity include pain, weakness, tightness and reduced functional capacity [8, 9].

Normal painfree motion of the arm and shoulder requires mobility in the scapulothoracic, glenohumeral, acromioclavicular and sternoclavicular joint [10]. The shoulder mechanism involves a combination of rotations and translations [11] about these four regions resulting in 3-dimensional (3-D) movement. However, recordings of 3-dimensional scapulothoracic motion are traditionally difficult to obtain due to the movement of the scapula and the clavicle beneath the skin. An electromagnetic motion tracking system (Polhemus Fastrak™) has been shown to be a valid, non-invasive technique for measuring 3-D motion of the scapula [12]. This system uses local co-ordinates set up with respect to the patients' body and expresses rotations of the scapula as Euler angles. The International Shoulder Group (ISB) protocol, adopted for standardising reporting of shoulder complex motion, uses a set sequence of rotations to allow for comparisons of results across studies [11]. This protocol describes a sequence of axes (Y, X′, Z″) about which the scapula rotates to describe lateral/medial rotation, anterior/posterior tilt and protraction/retraction during elevation of the arm. Under healthy conditions elevation of the arm is accompanied by scapula retraction, lateral rotation and posterior tilt [13–16].

However, when scapulothoracic motion is disproportionate to glenohumeral motion, the potential exists for microtrauma and long term pain [17]. A number of studies on women treated for breast cancer have shown limitations in glenohumeral range of movement [2, 6, 18, 19] and a recent report from our laboratory [20] has shown decreased muscle activity in four key muscles controlling scapula movement [serratus anterior (SA), upper trapezius (UT), pectoralis major (PM) and rhomboid (Rhom)]. The most notable reduction in activity was seen in UT and Rhom, both of which were associated with a high Shoulder Pain and Disability Index (SPADI). Furthermore we found both PM and PMinor to be reduced in size on the side of the cancer. These findings suggest alterations to the normal biomechanics of the shoulder complex. However, no study has measured the effect of treatment for breast cancer on 3-D scapulothoracic motion in relation to glenohumeral motion.

The primary aim of this study was to describe any differences in scapulothoracic kinematics between the affected and unaffected sides. Secondary aims were to evaluate associations between these data and the following covariates: degree of humeral elevation and direction of movement (up/down), age, time since surgery, medical treatment protocol, SPADI, chemotherapy, handedness, and whether left or right side was affected.

Method

This was a cross sectional study of patients treated for unilateral carcinoma of the breast. Ethical clearance was granted by the Oxfordshire Local Research Ethics Committee (A02, 064).

Participants

A power calculation for studies with correlated observations was employed to calculate the required number of patients to detect a difference of 4° [21] of scapula rotation for 24 observations per patient. A sample size of 131 patients each with 24 repeated observations (80% power; $\alpha = 0.05$, standard deviation of 9.98, and with interclass correlation of 0.85) was found to have sufficient power. 152 women meeting the inclusion and exclusion criteria (Table 1) consented to take part in the study. The time since surgery ranged from 6 months to 6 years.

Instrumentation

The Polhemus Fastrak™

Glenohumeral elevation in degrees was measured using an electromagnetic position and orientation movement tracking system. This comprises a three axis magnetic dipole source (or transmitter) and a three axis magnetic sensor (or receiver), together with related electronic equipment. The

Table 1 Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
Unilateral carcinoma of the breast	Reconstructive surgery
Treatment protocols[a]	
(1) Mastectomy	Current or previous history of shoulder complex trauma, surgery, pathology or dysfunction of the contra-lateral arm
(2) Mastectomy + radiotherapy	
(3) Mastectomy + radiotherapy + axillary radiotherapy	Lumpectomy
(4) Wide local excision + radiotherapy	Lymphoedema
(5) Wide local excision + axillary radiotherapy + radiotherapy	Current or previous history of cervical neuropathy
(6) Wide local excision + axillary clearance + radiotherapy	

[a] Mastectomy included modified radical mastectomy, radiotherapy = radiotherapy to the chest

sensors are small and lightweight and were attached to the skin as described previously with the exception of the thoracic sensor which was placed on T1 in our study [13]. Scapula and humeral surface mounted sensors have a root-mean-square (RMS) error of less than 5° when compared to sensors attached to bone pins [12, 13]. Within a 76 cm source- to- sensor separation, the RMS system accuracy is 0.15° for orientation and 0.3–0.8 mm for position [21]. The transmitter generates a low frequency magnetic field composed of three sequential excitation states, each of which produces an independent excitation vector.

The transmitter was attached to an upright plastic pole and used as the global reference frame. Patients were asked to stand within the frame and their bony landmarks digitised in order for the Polhemus Fastrak system to produce anatomical axes [15].

Shoulder pain and disability index

All patients filled in a SPADI questionnaire immediately prior to kinematic data being collected. The SPADI is a valid measure of pain and disability for shoulder dysfunction with high levels of sensitivity and reliability [22, 23]. The scale is a visual analogue scale with 13 items (5 for pain and 8 for disability). Total scores for pain range from a minimum of 0 mm to a maximum of 500 mm and for disability 0–800 mm. Zero representing no symptoms of pain or disability.

Arm elevation trials

Once the digitisation protocol was complete patients were asked to elevate their arm in the plane of the scapula, taken as 40° anterior to the coronal plane (scaption). With the patient standing, both arms were taken through three repeat movements of scaption, each one matched to a metronome at one complete cycle every 8 s (4 s to raise the arm and 4 s to lower the arm) and guided to remain in this plane by a flat surface oriented 40° anterior to the coronal plane. The patient was encouraged to elevate their arm as high as they could in a natural, relaxed manner and given three practise movements. This process was repeated on both sides and the side recorded first was randomly selected.

Reliability

Fastrak data collection was carried out by the same two observers (one applied sensors to patient and gave instructions, one operated the computer) blind to the SPADI data. Intrarater reliability was assessed by carrying out repeat measures on a different day for all movements for a random sample of five participants.

Data reduction and analysis

Descriptive analyses were conducted to assess demographic and clinical characteristics of the sample.

Scapula rotation and humeral elevation data from the three repeat scaption movements were averaged at every 10° interval of humeral elevation for subsequent analyses. The Motion Monitor^{TM} software system used in this study determines the orientation of the scapula relative to the trunk using the ISB protocol [11]. Angular rotations of the scapula were plotted as dependent variables against humeral elevation as the independent variable.

As these are paired observations for each individual, scapula measurement value of the unaffected arm was subtracted from scapula measurement value of affected arm for the scapulae of the same patients, at the same elevation point. Since strong associations between changes in measurements of the same scapula at two different elevation points (repeated measures) was observed, statistical analyses that accounted for these complex associations between observations were conducted.

Statistical analyses

Statistical analysis of Fastrak data utilised a linear mixed (random effect) model in order to account for the within class associations and to control for correlated observations [24].

Fastrak scapulothoracic measures for affected minus unaffected sides were the dependent variable and the following independent variables were included in the analysis: degree of humeral elevation and direction of movement (up/down), age, time since surgery, medical treatment protocol, SPADI (pain and disability), chemotherapy, handedness, and whether left or right side was affected. The corresponding values of the other two scapulothoracic measures were also included as independent variables in order to control for within scapula correlation. The correlations between repeated observations for each patient were controlled by introducing a patient specific random effect into the regression model. This regression can identify the subset of covariates which are significantly associated ($P \leq 0.05$) with a change in scapula measurement (i.e. change between affected and unaffected arm). The true magnitude of the difference between affected and unaffected sides, while controlling for the effects of all other prognostic factors, is reflected in the full linear mixed regression model analysis with all possible prognostic factors included.

Mean values for repeat measures of all scapulothoracic movements were used to determine intra-rater reliability for Fastrak measures using the Bland–Altman test [25].

SPADI

A separate one-way ANOVA was conducted to compare the individual items on the pain and disability indices for each of the time scales since surgery (0–2, 2–4, 4–6 years).

Results

Demographic and clinical details are shown in Table 2. The number of patients with left and right sides affected were closely represented. Intra-rater reliability for Fastrak procedures was 0.98.

Table 2 Demographic and clinical data for study sample ($n = 152$)

	Descriptive values
Number of patients	152
Duration since surgery—mean days (SD)	1144 (537)
Age—mean years (SD)	61.86 (8.99)
Affected side	
Left	48.4%
Right	51.6%
Handedness	
Left	8.6%
Right	91.4%
Dominant side affected	
Left	8%
Right	92%
Chemotherapy	
Yes	16.6%
no	83.4%
Mastectomy	13.6%
Mastectomy + radiotherapy	7.2%
Mastectomy + radiotherapy + axillary radiotherapy	9.2%
Wide local excision + radiotherapy	38.6%
Wide local excision + axillary radiotherapy + radiotherapy	18.3%
Wide local excision + axillary clearance + radiotherapy	13.1%
Total SPADI score—mean (SD)	166.24 (185.99)

SPADI data

Total SPADI scores as a function of time since surgery are shown in Table 3. No significant difference between years was shown but both pain and disability scores are higher at the 4–6 year interval.

Analysis of pain and disability as a function of side affected revealed significantly higher levels of pain reported by patients with left side affected (Table 4).

This was further broken down to determine which of the three sub-categories of pain intensity was most likely to be contributing to this result (Table 5). The greatest percentage of patients reporting pain over 50 mm were left side affected while the greatest percentage of patients reporting pain less than 30 mm were right side affected. Patients with the left side affected show a slightly higher percentage of more aggressive treatment protocols (Table 6).

Kinematic data

Figures 1, 2, and 3 represent the patterns of scapulothoracic movement during elevation and depression of the arm. For within subject comparisons the right affected graph should be compared with the left unaffected graph

Table 4 Difference between mean pain and disability scores for side affected

	Side affected	Mean	SD	SEM	*P* value
SPADI pain (mm)	Left	82.90	89.72	2.04	0.000
	Right	70.49	90.15	2.08	
SPADI disability (mm)	Left	81.59	86.01	1.96	0.45
	Right	80.23	100.28	2.31	

Table 5 Sub-categories of mean pain scores as a function of side affected

Pain (mm)	Left side affected (%)	Right side affected (%)
0–30	42.7	57.3
30–50	24.7	75.3
>50	56.8	43.2

Table 3 Total pain and disability scores as a function of time intervals

Groups	*N*	Minimum (mm)	Maximum (mm)	Mean (mm)	SD (mm)	Between group *P*-value
Pain 0–2 years	39	0.00	256.00	73.59	75.63	0.324
Pain 2–4 years	65	0.00	365.00	71.26	89.44	
Pain 4–6 years	49	0.00	364.00	96.49	110.48	
Dysfunction 0–2 years	39	0.00	369.00	68.62	79.91	0.289
Dysfunction 2–4 years	65	0.00	417.00	83.46	100.91	
Dysfunction 4–6 years	49	0.00	367.00	101.96	110.24	

Table 6 Distribution of treatment variables for side affected

	Percentage of left side affected	Percentage of right side affected
Mastectomy	15	13
Mastectomy + radiotherapy	10	5
Mastectomy + chest radiotherapy + axillary radiotherapy	7	11
WLE + chest radiotherapy	35	42
WLE + chest radiotherapy + axillary clearance	16	20
WLE + axillary radiotherapy + chest radiotherapy	17	9
Received chemotherapy	19	15

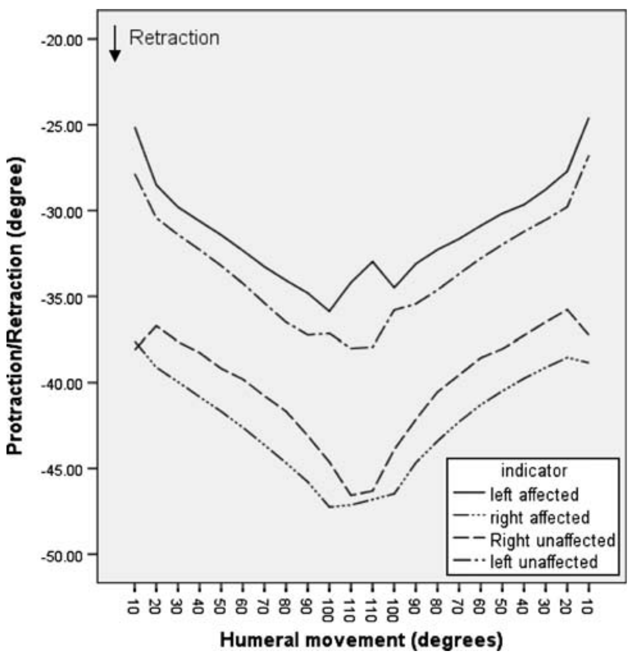

Fig. 1 Mean scapula protraction/retraction plotted against humeral elevation and depression for affected and unaffected sides ($n = 152$). *Arrow* represents direction of retraction. Difference between affected and unaffected arm is significant ($P = 0.034$)

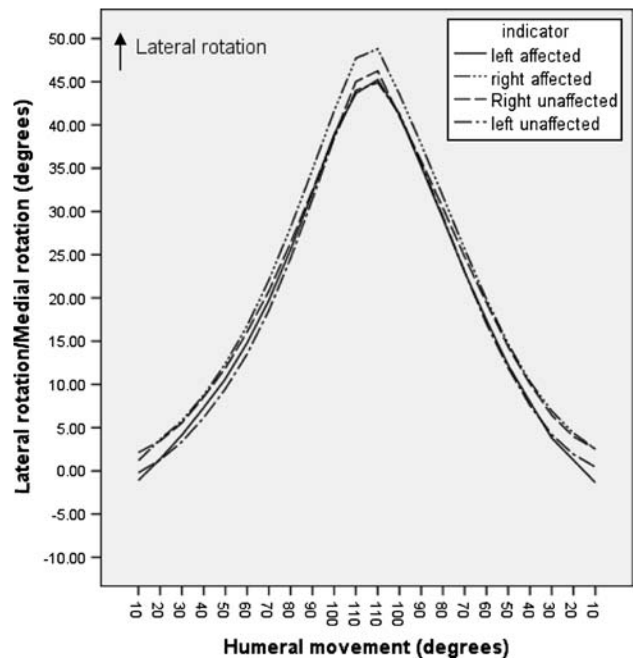

Fig. 2 Mean scapula lateral/medial rotation plotted against humeral elevation and depression for affected and unaffected sides ($n = 152$). *Arrow* represents direction of lateral rotation. Difference between affected and unaffected arm is significant ($P = 0.000$)

and visa versa. The pattern of movement for scapula protraction/retraction and rotation shows opposite effects when the right side is affected (Figs. 1, 3). Without controlling for the effects of other prognostic factors only the difference between anterior/posterior tilt of the affected and unaffected sides is not significant. Once prognostic factors are considered this becomes a significant difference (Tables 7, 8, and 9). Thus the averages shown in these figures do not accurately reflect the actual observed variation in shoulder movement between subjects because the effects of the prognostic factors have not been controlled.

The effects of other prognostic factors, is better reflected in the regression analysis for longitudinal outcomes with all possible prognostic factors included.

All scapulothoracic movements were significantly altered on the affected side compared to the unaffected side and were independent of the type of medical management. The difference was significantly larger when the left side was affected (Tables 7, 8, and 9). No effect for hand dominance was found and an exploration of radiotherapy delivery did not reveal any general protocol differences for the left side. Left scapulothoracic dysfunction included increased protraction, increased posterior tilt and decreased lateral rotation, all of which were significantly associated with having had chemotherapy (Tables 7, 8, and 9). Right scapulothoracic dysfunction included increased retraction, increased posterior tilt and increased lateral rotation. Only scapulothoracic lateral rotation differences were associated with the downward movement (Table 9).

Both pain and disability were significantly associated with scapulothoracic dysfunction (Tables 7, 8, and 9).

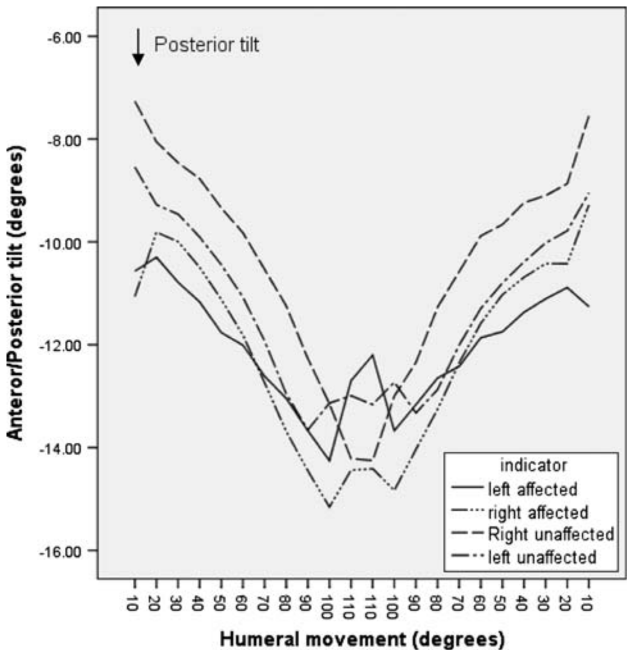

Fig. 3 Mean scapula anterior/posterior tilt plotted against humeral elevation and depression for affected and unaffected sides ($n = 152$). *Arrow* represents direction of posterior tilt. Difference between affected and unaffected arm is not significant ($P = 0.518$)

Table 7 Random effects multiple regression for associations between scapula protraction/retraction and covariates

Protraction/retraction	Coef.	Sig	(95% Conf. interval)	
Left side affected	20.38	0.001	8.45	32.30
Pain score	−0.13	0.035	−0.25	−0.00
Received chemotherapy	19.19	0.022	2.81	35.56
Lateral/medial rotation	0.21	0.000	0.16	0.26
Anterior/posterior tilt	0.65	0.000	0.60	0.69
Constant	25.29	0.305	−23.08	73.68

Dependent variable: scap protraction/retraction affected-unaffected, reference category for treatment was WLE + Radiotherapy. Only significant variables are shown

Table 8 Random effects multiple regression for associations between scapula anterior tilt/posterior tilt and covariates

Anterior/posterior tilt	Coef.	Sig	(95% Conf. interval)	
Left side affected	−15.38	0.001	−24.67	−6.08
Pain score	0.11	0.017	0.02	0.21
Disability score	−0.10	0.022	−0.20	−0.01
Received chemotherapy	−14.52	0.026	−27.27	−1.77
Protraction/retraction	0.67	0.000	0.65	0.70
Lateral/medial rotation	−0.18	0.000	−0.21	−0.16
Constant	−20.95	0.27	−58.61	16.71

Dependent variable: scap anterior tilt/posterior tilt affected-unaffected, reference category for treatment was WLE + Radiotherapy. Only significant variables are shown

Table 9 Random effects multiple regression for associations between scapula lateral rotation/medial rotation and covariates

Lateral/medial rotation	Coef.	Sig	(95% Conf. interval)	
Downward movement	−0.45	0.00	−0.74	−0.15
Higher degree of elevation	0.20	0.00	0.15	0.24
Left side affected	−8.58	0.00	−13.15	−4.02
Pain score	0.05	0.02	0.00	0.10
Disability score	−0.05	0.02	−0.09	−0.00
Received chemotherapy	−7.82	0.01	−14.02	−1.61
Pro/retraction	0.23	0.00	0.18	0.27
Anterior/posterior tilt	−0.20	0.00	−0.25	−0.16
Constant	−12.44	0.18	−30.65	5.76

Dependent variable: scap lateral rotation/medial rotation affected–unaffected, reference category for treatment was WLE + Radiotherapy. Only significant variables are shown

Discussion

This study has shown altered movement patterns in the shoulders of patients treated for breast cancer. Irrespective of the side affected, patients in this study reported pain levels sufficient to interfere with ADL [26–28] for up to 6 years after surgery.

The most significant finding is the presence of higher levels of reported pain in patients with the left side affected. This evidence of pain lateralisation was unrelated to handedness which supports findings under different conditions [29, 30]. A number of studies have reported increased frequency of pain on the left side with higher intensity and lower tolerance threshold than on the right [31, 32]. Furthermore, a functional asymmetry towards the right hemisphere for pain perception has been reported by several authors [29, 32]. The right hemisphere is also dominant in processing emotional experience [33], suggesting a possible link between the right hemisphere and the emotional component of pain processing. This is supported by evidence that factors such as anxiety and anticipation of pain have been shown to stimulate affective/cognitive pain perception pathways [34–36]. Indeed anxiety is a risk factor for pain in breast cancer [7] and a recent review has demonstrated effective management of pain in breast cancer patients with the use of CBT [37]. In the absence of any general difference in medical protocol, assigning high intensity left sided pain to a more affective/cognitive origin is tempting.

However, pain perception is not that simple and is known to be a subjective experience dependent upon emotional, chemical and physical factors [38]. Radiotherapy and chemotherapy both have the potential to induce cell damage and promote chemical nociceptor stimulus via pro-inflammatory cytokines [39, 40]. Additionally, physical changes in muscle and joint movement have been shown in our studies [20]. Since decreased pain threshold on the left has consistently been shown to apply to deep pressure stimuli such as that transmitted by muscle nociceptors [29, 41], it is possible that high levels of pain in left side affected patients is due to muscle nociceptor stimulation. Right side affected patients may overcome some pain and dysfunction due to the need to use the dominant arm. This use of the arm may also account for the observed increased *retraction* of the scapula which would assist with raising the arm. If this is the case it is possible that a protective, limited movement dysfunction is leading to higher levels of perceived pain on the left. This area needs further research in order to fully understand why some women develop increased pain and what makes left side affected patients at risk of developing higher levels of pain and dysfunction.

Altered movement shown in our studies could be the physical manifestation of either pain pathway or may themselves induce pain. UT and SA work as a force couple to protract elevate and laterally rotate the scapula thereby ensuring clearance of the subacromial arch [10]. The loss of UT and SA activity previously shown would alter the force couple produced by these muscles, decreasing upward rotation of the scapula [14, 42]. Decreased upward rotation has been implicated in impingement syndrome [43, 44] and glenohumeral instability [45, 46]. Although impingement is generally associated with anterior scapula tilt, the possibility of different sites of impingement has been raised [43] and may be associated with different angles of tilt. Analysis of all scapula movements has shown that lateral rotation is the most important kinematic parameter associated with dysfunction in shoulder disorders [47]. The increased posterior tilt seen in this study might therefore be a compensatory movement to increase the subacromial space due to the loss of lateral rotation. This loss of lateral rotation was enhanced on the downward or eccentric movement of the arm suggesting poor muscle control of the scapula. Breast cancer patients are clearly demonstrating movement dysfunction which mimics that found in common shoulder conditions. Our laboratory is currently looking at concomitant muscle control of scapula kinematic parameters.

Conclusion

Patients treated for breast cancer have shown significant pain and movement dysfunction at the shoulder complex. Those patients with the left side carcinoma should be recognised as a group most likely to develop higher levels of pain and dysfunction after treatment. The most important clinical implication is that until we know more about the mechanisms causing pain and dysfunction, any package of care should consider a cognitive behavioural approach and include strategies for region specific rehabilitation as well as general health and well being of the breast cancer survivor.

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