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**ORIGINAL COMMUNICATION**

# Clinical Anatomy of the Shoulder After Treatment for Breast Cancer

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Normal painfree movement of the upper limb requires movement at the glenohumeral joint and movement of the scapula on the thorax. Co-ordinated movement of these joints is known as the scapulohumeral rhythm and is required during elevation of the arm. Coordinated movement is further achieved by timing of the many muscles acting across the joints. A pilot study from our laboratory has shown significant alterations to this scapulohumeral rhythm and its muscle control following treatment for breast cancer. The aims of this study were to: (1) correlate altered muscle activity from a larger sample with observed movement deviations; (2) compare movement and muscle deviations in survivors with a healthy population and (3) explore the impact of a mastectomy versus a wide local excision (WLE) on the observed deviations. Cross-sectional study. 155 women treated for unilateral carcinoma of the breast and 21 age-matched healthy women were included in the study. All patients filled out the Shoulder Pain and Disability Index (SPADI). Three-dimensional kinematic data and EMG muscle activity were recorded during scaption on the affected and unaffected side. Patients demonstrated a different movement dysfunction depending on whether the left or the right shoulder was affected. Left affected shoulders demonstrated the greatest degree of internal rotation of all shoulders studied. Compared to healthy shoulders patients following a mastectomy demonstrated increased activity in both the left and right affected shoulders in all the measured muscles. In patients having a WLE, such increases were not observed in serratus anterior and pectoralis major activity on the right affected shoulder, where a decrease was noted. Muscle dysfunction was also observed in the unaffected side of patients. Having received chemotherapy contributed significantly to the difference seen between the affected and unaffected shoulders in patients. Differences in scapular tilt between affected and unaffected shoulders in patients were significantly associated with pain and disability, and changes in serratus anterior activity. Patterns of movement deviation resemble those seen in known shoulder conditions. Anatomical and biomechanical evidence supports the need for integrated rehabilitation and surveillance systems for the shoulder in oncology units. Clin. Anat. 27:467–477, 2014. 

**Key words: kinematics; shoulder; EMG; mastectomy; WLE; breast cancer**

## INTRODUCTION

Normal painfree movement of the upper limb requires movement at the glenohumeral joint and movement of the scapula on the thorax

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**TABLE 1. Inclusion and Exclusion Criteria**

| Inclusion criteria | Exclusion criteria |
|---|---|
| Unilateral carcinoma of the breast. Treatment protocols: | |
| (1) Mastectomy | Reconstructive surgery |
| (2) Mastectomy + radiotherapy | Previous history of shoulder complex trauma, surgery, pathology or dysfunction on affected side |
| (3) Mastectomy + radiotherapy + axillary radiotherapy | Current or previous history of shoulder complex trauma, surgery, pathology or dysfunction on contralateral side |
| (4)Wide local excision + radiotherapy | Current or previous history of cervical neuropathy on either side |
| (5)Wide local excision + axillary radiotherapy + radiotherapy | Lumpectomy |
| (6)Wide local excision + axillary clearance + radiotherapy | Lymphoedema |

(Ludewig et al., 1996). Scapula movement occurs at the sternoclavicular and acromioclavicular joints (Ludewig et al., 1996; Dayanidhi et al., 2006). Co-ordinated movement of these joints is required during elevation of the arm and is achieved by timing of the many muscles acting across the joints (Donatelli, 2000). The subsequent rhythm that is produced is known as the scapulohumeral rhythm. Three phases of shoulder elevation have been described: the initial phase (0°–60°); the middle or "critical phase" (60°–140°) and the final phase (140°–180°) (Donatelli, 2000). Alterations to normal scapulohumeral rhythm have been associated with common shoulder conditions such as rotator cuff disorders and adhesive capsulitis (Ludewig and Cook, 2000; Hebert et al., 2002; Mell et al., 2010; Fayad et al., 2008; Ludewig and Reynolds, 2009).

Women treated for breast cancer often complain of shoulder pain and decreased function post-surgery; 10–55% of women show restricted glenohumeral range of movement, 22–38% complain of shoulder pain, and 42–56% report difficulties with lifting the upper limb (McNeely et al., 2010). Despite the evidence of shoulder morbidity following surgery for breast cancer, our group have been the first to assess shoulder kinematics and muscle function after surgery in this patient population. Pilot results from our team have described scapulohumeral deviations and altered muscle activity associated with pain and dysfunction in a small sample of breast cancer patients (Shamley et al., 2007, 2009). These findings were based on a small sample and were not compared to a healthy population.

The aims of this study were to (1) Correlate altered muscle activity from a larger sample with observed movement deviations; (2) Compare within subject movement and muscle deviations in survivors with a healthy population; (3) Explore the impact of a mastectomy versus a wide local excision (WLE) on the observed deviations.

## MATERIALS AND METHODS

Following Ethical clearance by the Oxfordshire Local Research Ethics Committee (A02,064), a cross sectional study comparing patients with shoulder pain treated for unilateral carcinoma of the breast and a sample of healthy women was conducted.

**TABLE 2. Demographic and Clinical Data for Study Sample (*n* = 176)**

| | Descriptive values | |
|---|---|---|
| Control Group; Sample size 21 | | |
| | Mean | (SD) |
| Age (year) | 53.10 | (6.09) |
| Handedness: | Frequency | (%) |
| Left | 2 | (10%) |
| Right | 19 | (90%) |
| Patient Group; Sample size 155 | | |
| | Mean | (SD) |
| Duration since surgery (days) | 1,143.81 | (534.77) |
| Age (year) | 61.66 | (9.13) |
| Total SPADI score | 168.10 | (185.74) |
| Affected side: | Frequency | (%) |
| Left: WLE | 50 | (32%) |
| Mastectomy | 22 | (14%) |
| Right: WLE | 56 | (36%) |
| Mastectomy | 22 | (14%) |
| Missing | 5 | (03%) |
| Handedness: | | |
| Left: WLE | 9 | (6%) |
| Mastectomy | 5 | (3%) |
| Right: WLE | 97 | (64%) |
| Mastectomy | 39 | (26%) |
| Missing | 1 | (<1%) |
| Dominant side affected | | |
| Yes | 79 | (51%) |
| No | 75 | (48%) |
| Missing | 1 | (<1%) |
| Chemotherapy | | |
| Yes | 24 | (15%) |
| No | 127 | (84%) |
| Missing | 4 | (<3%) |
| Treatment | | |
| Mastectomy | 21 | (14%) |
| Mastectomy + radiotherapy | 12 | (08%) |
| Mastectomy + radiotrapy + axillary | 14 | (09%) |
| Wide local excision + radiotherapy | 60 | (39%) |
| Wide local + excision + axillary + radiotherapy + radiotherapy | 20 | (13%) |
| Wide local excision + axillary + clearance + radiotherapy | 28 | (18%) |

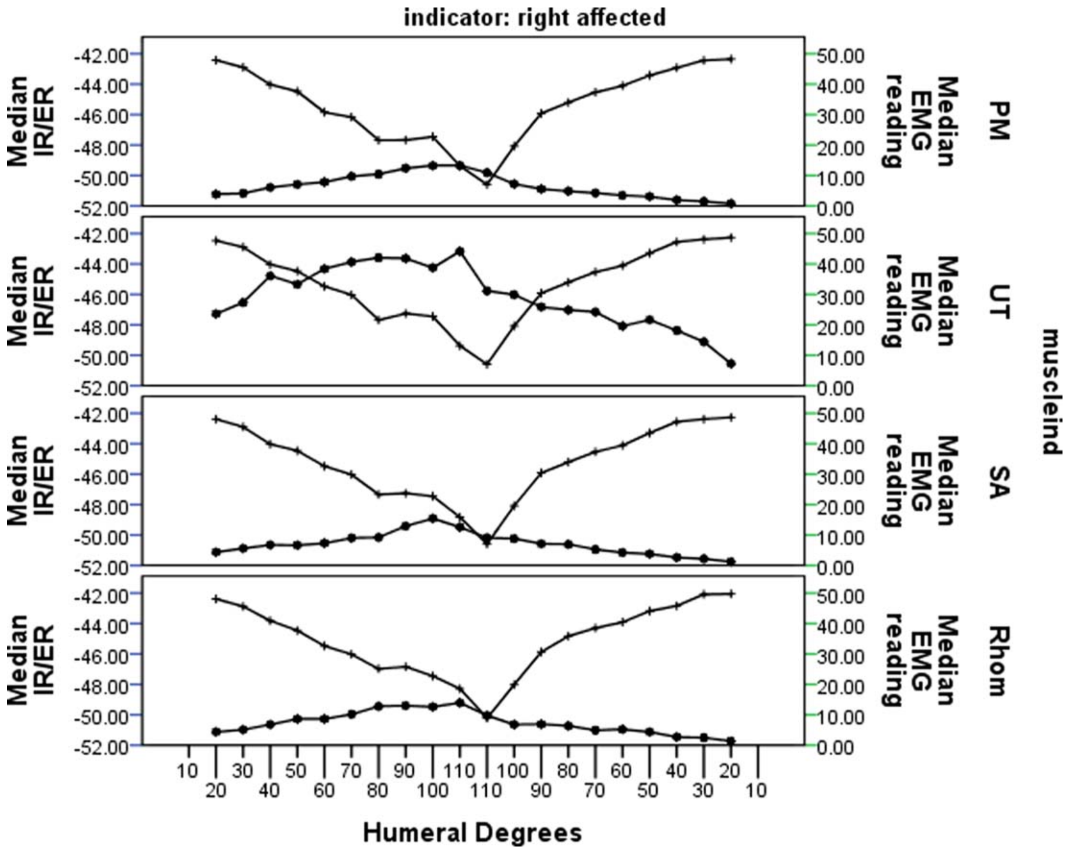


**Fig. 1**. EMG muscle activity during IR/ER of the scapula on the right affected side. Key: EMG = •–•–•, Scapular degrees = ×–×–×, and External Rotation = ↓. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

## Participants

A power calculation for studies with correlated observations was employed to calculate the required number of patients to detect a difference of 4° (Lukasiewicz et al., 1999) 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. Patients that had undergone surgical treatment for breast cancer were offered to participate in the study and screened for inclusion criteria by a breast care nurse. Healthy women were recruited locally through an advert. 155 women treated for breast cancer and 21 healthy women volunteered to take part in the study. The inclusion/exclusion criteria for the group of women with a history of breast cancer surgery are listed in Table 1. In the comparison group, women were included if they had no history of cancer, shoulder or neck pain on either side.

## Instrumentation

Described in detail in Shamley et al. 2007.

## Kinematic Data

The 3 Space Fastrak® three-dimensional motion analysis system was used to measure shoulder kinematics. This system is formed by a transmitter that emits an electromagnetic field and four receivers. Within a 76 cm source-to-sensor separation the root mean square (RMS) system accuracy is 0.3–0.8 mm for position and 0.15° for orientation (Polhemus Inc., 1993; Karduna et al., 2001). Global and local coordinate systems were set up as described by the International Shoulder Group (ISG) protocol (Wu et al., 2005).

**Electromyography.** Muscle activity of the pectoralis major (PM), serratus anterior (SA), rhomboids(Rhom) and upper trapezius (UT) muscles was measured using surface electromyography (SEMG). These muscles have been associated with shoulder

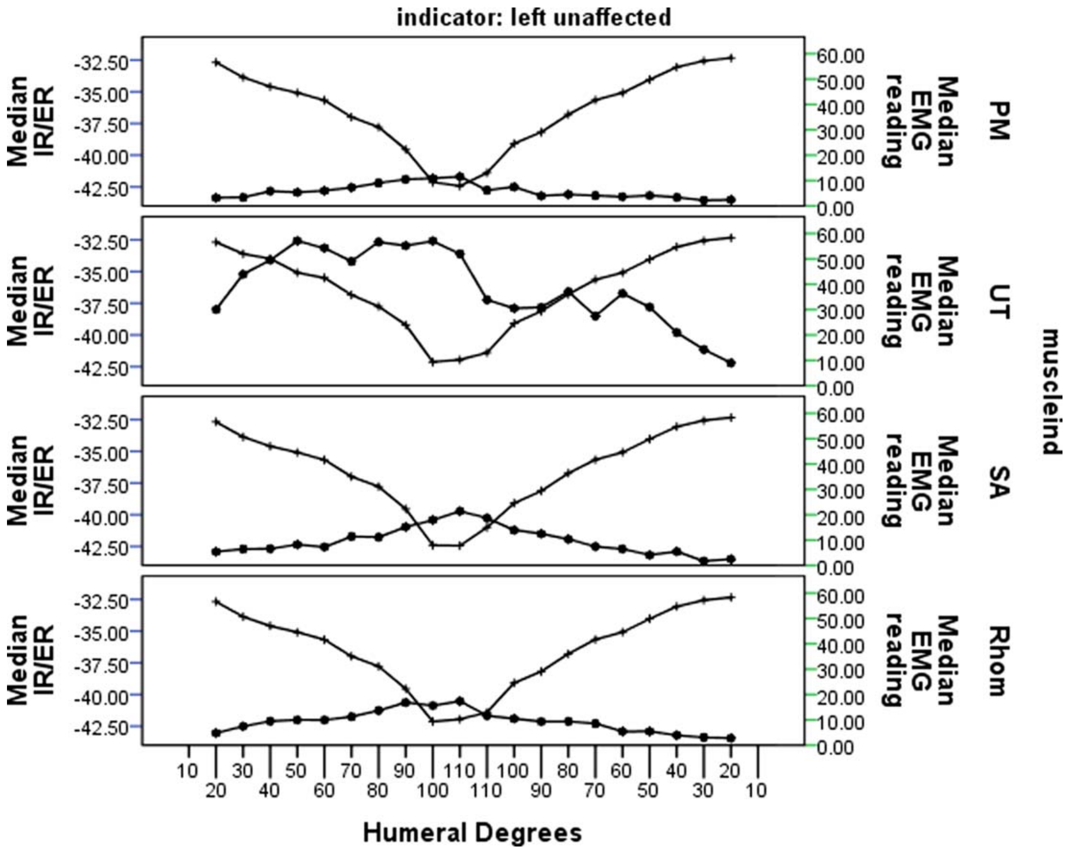


**Fig. 2**. EMG muscle activity during IR/ER of the scapula on the left unaffected side. Key: EMG = •–•–•, Scapular degrees = ×–×–×, and External Rotation = ↓. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

pain and pathology (Ludewig and Cook, 2000; Kibler and McMullen, 2003; Labriola et al., 2005). In standing, pre-gelled silver-silver chloride SEMG electrodes (Maersk Medical) were attached over the prepared skin sites, parallel to the muscle fibers as previously described (Ludewig et al., 1996). Reference electrodes were placed on electrically neutral tissues. SEMG signal quality was verified by having the participant perform a resisted contraction in the manual muscle testing position specific to each of the muscles being tested (Kendall et al., 2005).

**Arm elevation trials.** Patients were instructed to elevate their arm in the plane of the scapula (40° from the coronal plane) at a pace dictated by a metronome, where a complete cycle of elevation and depression of the arm took 8 sec, that is, 4 sec for elevation and 4 seco for depression. A flat surface oriented in this plane guided the subject's arm through the movement. Full kinematic data of three repeated elevation and depression movements of the arm were collected. This process was repeated with each arm. The side to be measured first was randomly selected.

**Shoulder pain and disability index.** All patients completed the SPADI pain and disability questionnaire immediately prior to the arm elevation trials. The SPADI comprises 13 visual analogue scales, five make reference to pain and eight to disability. The SPADI questionnaire has been found to be both sensitive and reliable to measure shoulder dysfunction (Williams et al., 1995).

**Reliability.** Two observers blind to the SPADI questionnaire data carried out the kinematic and SEMG data collection. Reliability was assessed by carrying out a repeat of all measures on a different day for a randomly selected sample of five subjects.

**Data reduction and analysis.** The MotionMonitor™ software was used to simultaneously collect and synchronize shoulder SEMG and kinematic data. Furthermore, this software allowed the output from the three Space Fastrak® to be transformed into angular rotations of the scapula and the humerus relative to the trunk as determined by the ISG protocol (Wu et al., 2005). Scapular rotation was plotted as a dependent variable against thoracohumeral elevation as the independent variable. Analysis of the data only included thoracohumeral elevation of up to 110°, as the error of the scapular sensor increases beyond this point. To allow for international comparisons to be made terminology used to describe scapula motion in this report differs from our previous report and includes internal/external rotation (protraction/retraction) and upward/

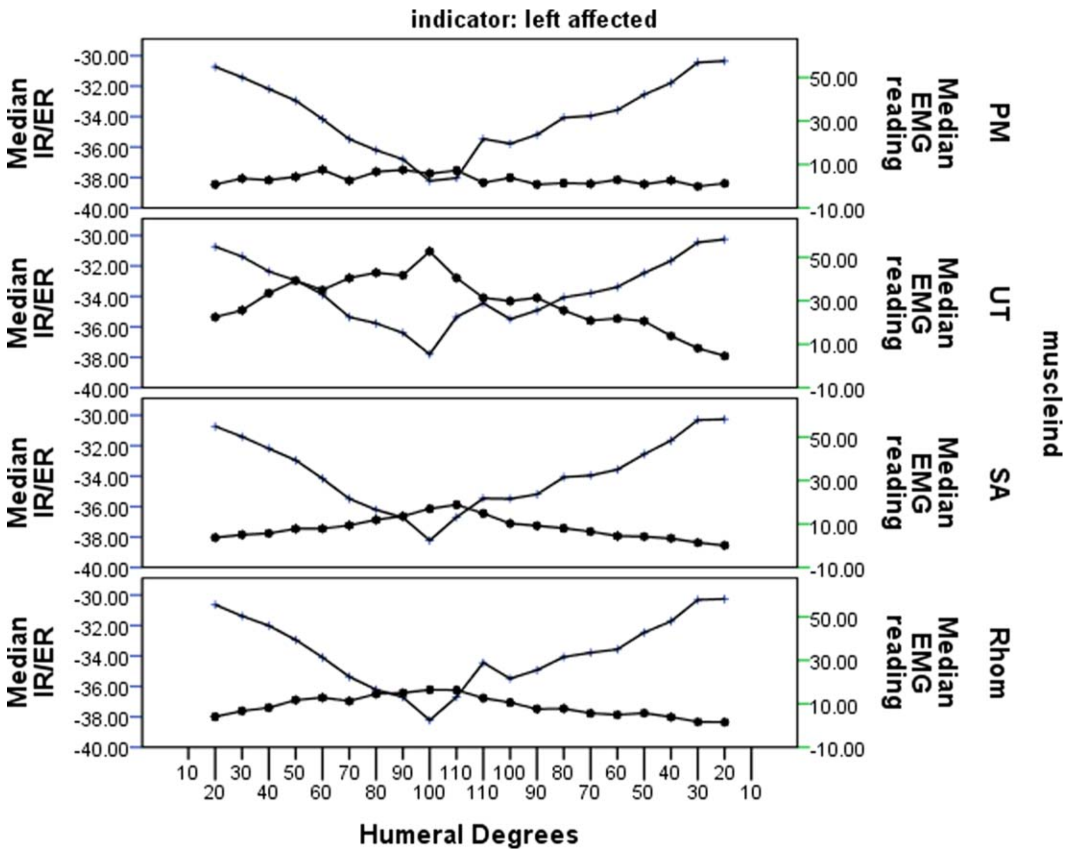


**Fig. 3**. EMG muscle activity during IR/ER of the scapula on the left affected side. Key: EMG = ●–●–●, Scapular degrees = ×–×–×, and External Rotation = ↓. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

downward rotation (lateral/medial rotation). Anterior/posterior tilt remains the same.

For EMG data a normalization reference was collected for 1 min at rest for each muscle. Following this, average root mean square (RMS) movement values minus the RMS resting value were determined. Data of all three arm elevation trials were averaged for the scapular position and muscle EMG reading at every 10° interval of thoracohumeral elevation.

**Statistical analysis.** Fastrak parameters for affected minus unaffected sides were the dependent variable and clinical and demographic data were the independent variables. In order to simultaneously model all three scapular motions of the same patient a two-stage, linear mixed model analogous to the model proposed by Weiner et al. 2002 was used. Stage one utilized a linear mixed model fitted to each scapular motion to determine residual values representing the amount of variation in that particular scapular motion that cannot be explained by collective effect of all predictor variables. In stage two each dependent variable was modelled by another linear mixed model while the residuals obtained in stage one were included in the model as risk factors.

General linear regression models were used to assess any differences between scapular movements and mastectomy versus wide local excision (WLE). Bland-Altman methods were used to determine intrarater reliability for Fastrak and EMG measures.

## RESULTS

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

Healthy scapulae showed greater external rotation (ER) and greater upward rotation (UR) on the right versus the left. These differences between left and right sides were also observed in patients treated for breast cancer. Both shoulders in patients demonstrated movement deviations over and above normal variation and these are discussed in Shamley et al. 2012.

### Affected versus Unaffected arm Movement Evaluation

**Patterns of muscle activity and kinematics of the scapula.** ***Right side affected versus left unaffected side.*** When the right side is affected the scapula has a greater externally rotated and

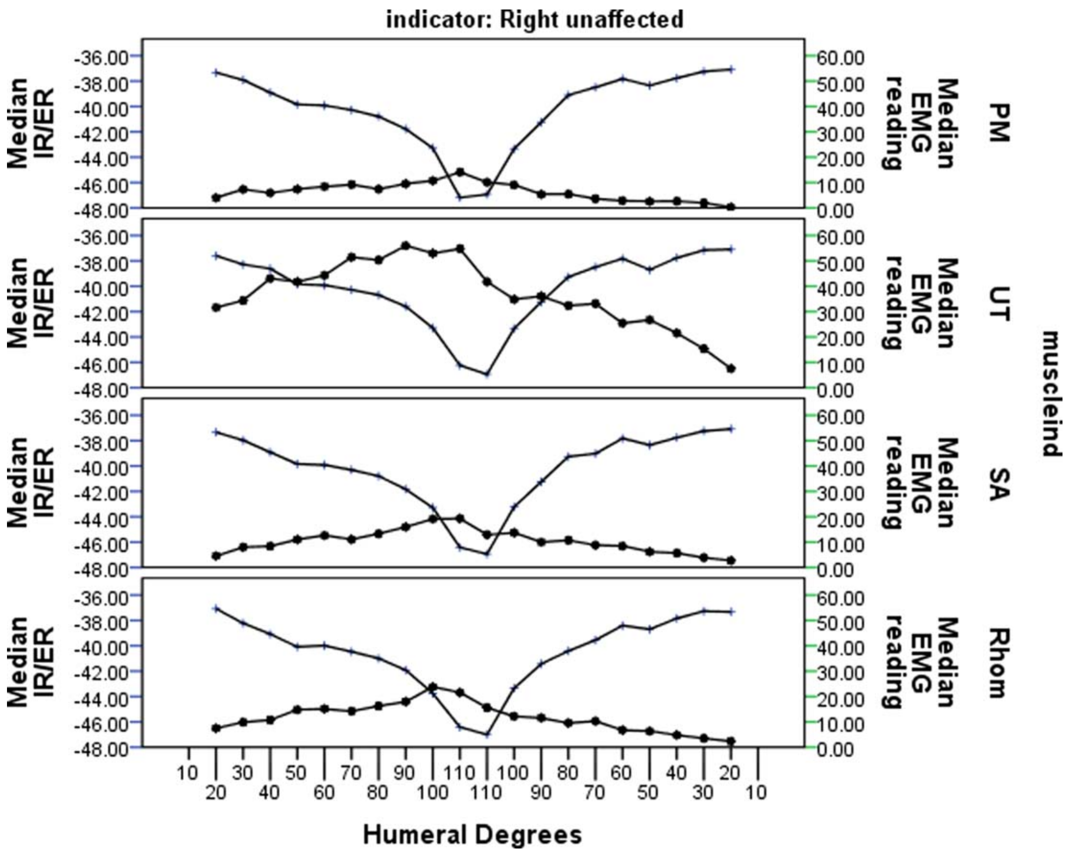


**Fig. 4**. EMG muscle activity during IR/ER of the scapula on the right unaffected side. Key: EMG = •–•–•, Scapular degrees = ×–×–×, and External Rotation = ↓. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

anteriorly tilted (not shown) starting position and remains more externally rotated throughout the movement (Figs. 1 and 2). The movement into posterior tilt is delayed over the first 50° of elevation. This movement pattern is accompanied by (1) reduced muscle activity in UT (notably on raising of the arm) (concentric activity), (2) increased activity in PM, and (3) earlier release of SA activity particularly at the change from concentric to eccentric muscle work.

***Left side affected versus right unaffected side.*** During elevation the left affected side loses approximately 10° of external rotation, and shows a reduced range of posterior tilt (not shown) during the critical phase of elevation (80°–120°) and on lowering the arm (Figs. 3 and 4). This pattern is accompanied by

**TABLE 3. Two Stage, Random Effects Multiple Linear Regression for Assessing the Effect of Covariates (Risk Factors) on Scapula Internal/External Rotation**

| | Coef. | Std. Err. | *z* | *P* value | [95% Conf. Interval] | |
|---|---|---|---|---|---|---|
| Side affected (left) | 17.69835 | 5.737425 | 3.08 | 0.002 | 6.453198 | 28.94349 |
| Chemotherapy (yes) | 17.38926 | 7.815886 | 2.22 | 0.026 | 2.070404 | 32.70812 |
| UT effect | −0.0061914 | 0.0017575 | −3.52 | 0.000 | −0.0096362 | −0.0027467 |
| SA effect | 0.0070949 | 0.0028003 | 2.53 | 0.011 | 0.0016064 | 0.0125834 |
| Up/down rot Residuals | 0.1946942 | 0.0139525 | 13.95 | 0.000 | 0.1673478 | 0.2220406 |
| At/Pt Residuals | 0.6427942 | 0.0144075 | 44.62 | 0.000 | 0.614556 | 0.6710325 |
| Intercept | 19.7621 | 23.09957 | 0.86 | 0.392 | −25.51222 | 65.03642 |

Dependent variable: scap internal/external rotation affected—unaffected, reference category for treatment was WLE + Radiotherapy. Only significant variables shown. Number of observations = 2,728, Number of patients = 149, six observations dropped due to missing covariates. Log likelihood = −7436.63. Model *P* value = 0.000. UT—upper trapezius; SA—serratus anterior.

**TABLE 4. Two Stage, Random Effects Multiple Regression for Assessing the Effect of Covariates (Risk Factors) on Scapula Anterior/Posterior Tilt**

| | Coef. | Std.Err. | Z | P_value | [95% Conf. Interval] | |
|---|---|---|---|---|---|---|
| Upward arm movement | 0.2815034 | 0.1188529 | 2.37 | 0.018 | 0.048556 | 0.5144508 |
| Spadi Pain effect | 0.0477709 | 0.0231911 | 2.06 | 0.039 | 0.0023171 | 0.0932247 |
| Spadi disab. Effect | −0.0490682 | 0.0221916 | -2.21 | 0.027 | −0.092563 | −0.0055733 |
| Wleaxcl Treatment | 9.178385 | 4.501797 | 2.04 | 0.041 | 0.3550238 | 18.00175 |
| SA effect | 0.0096405 | 0.0029959 | 3.22 | 0.001 | 0.0037688 | 0.0155123 |
| Int/Ext rot Residuals | 0.6787733 | 0.0151915 | 44.68 | 0.000 | 0.6489985 | 0.708548 |
| Up/down rot Residuals | −0.1697199 | 0.0144681 | −11.73 | 0.000 | −0.1980768 | −0.141363 |
| Intercept | −7.209109 | 9.02434 | −0.80 | −0.424 | −24.89649 | 10.47827 |

Dependent variable: scap anterior/posterior tilt affected - unaffected, reference category for treatment was WLE + Radiotherapy. Only significant variables shown. Number of observations = 2,728, Number of patients = 149, six observations dropped due to missing covariates. Log likelihood = −7362.99. Model *P* value = 0.000.

(1) a lower starting level of contraction in UT, markedly less UT activity during the critical phase and a sudden prolonged drop in contraction on lowering the arm, (2) a drop in activity of rhomboid, (3) relatively normal activity of SA and (4) lower PM activity.

Having received chemotherapy further contributes significantly to the difference seen between the affected and unaffected shoulders in patients (Table 3). Changes in SA and UT activity were significantly associated with the differences in external rotation of affected and unaffected shoulders (Table 3).

Differences between tilt of affected and unaffected shoulders in patients were significantly associated with pain and disability and changes in SA activity (Table 4).

**Muscle activity in patients having mastectomy versus WLE.** Figures 5–8 clearly demonstrate a difference in muscle activity between healthy participants and mastectomy and WLE patients. Furthermore the

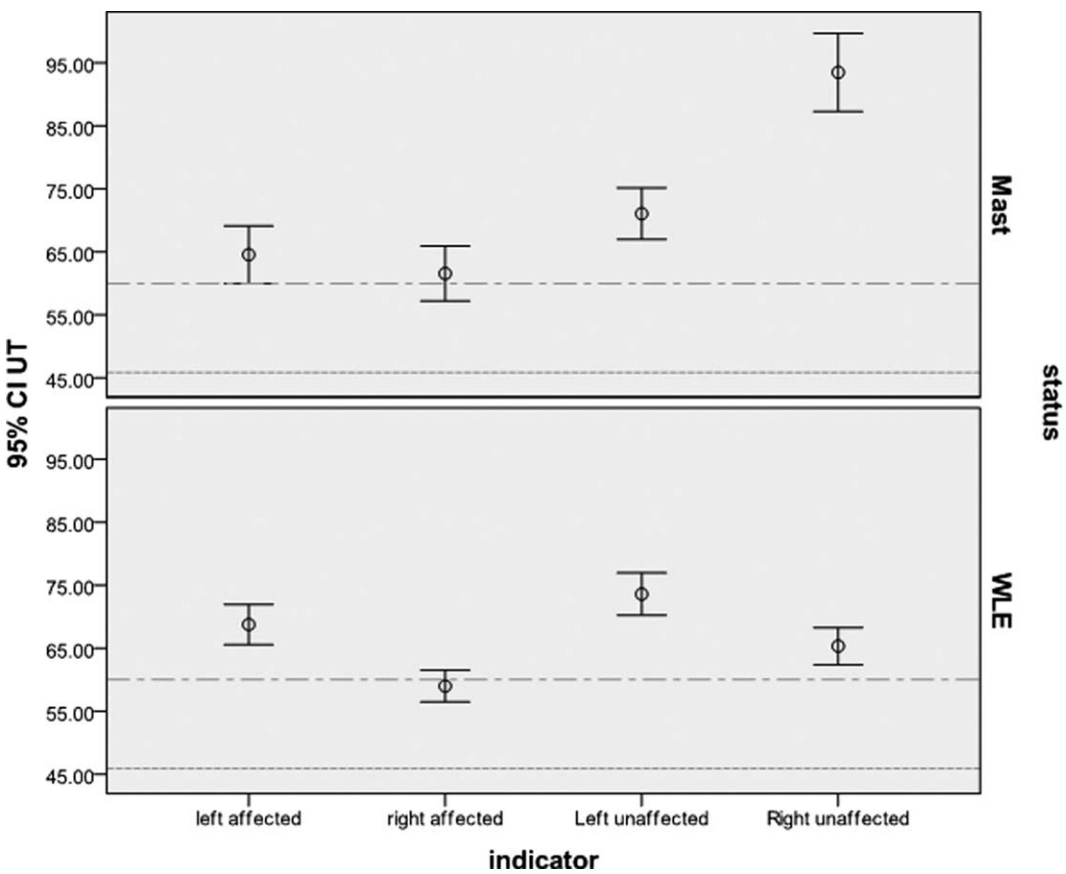


**Fig. 5**. EMG activity in Upper Trapezius for healthy participants and patients (Mean and SD). Key: Right healthy UT = ········ and Left healthy UT: -·-·-·-·-·-·-·.

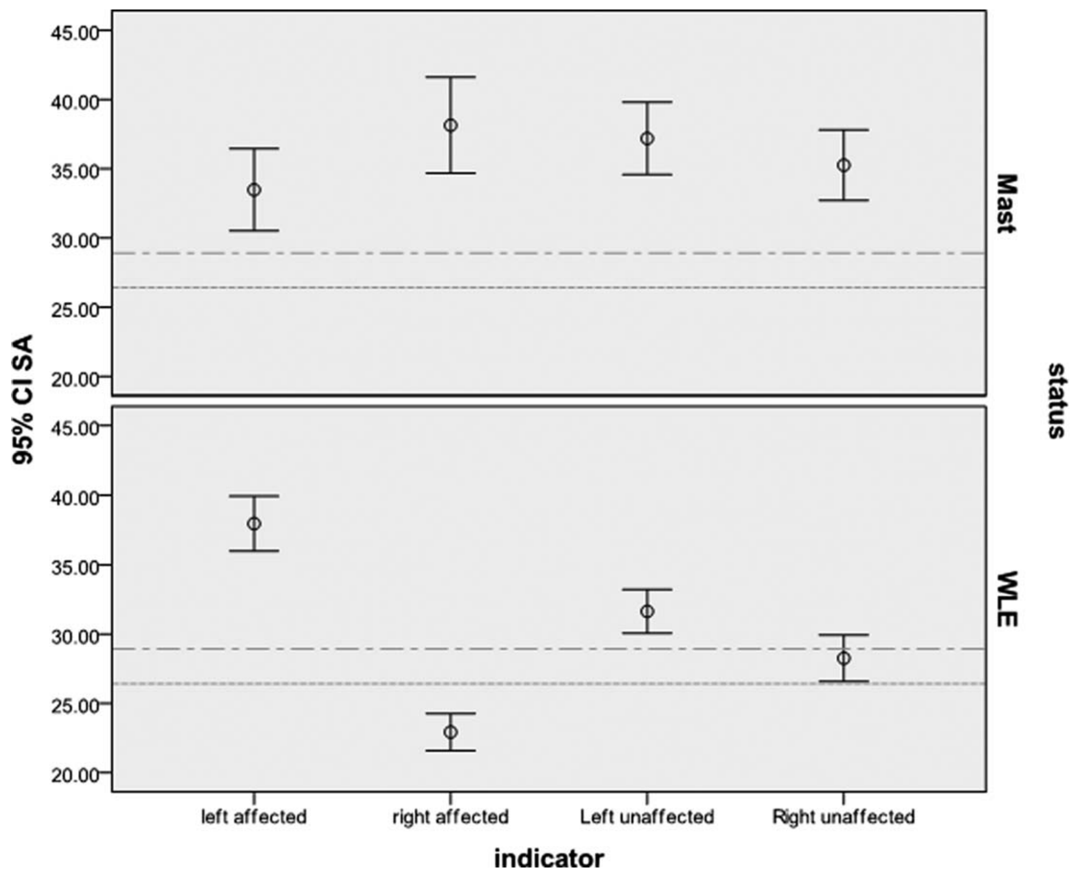


**Fig. 6**. EMG activity in Serratus Anterior for healthy participants and patients (Mean and SD). Key: Right healthy SA = ·········· and Left healthy SA = -·-·-·-·-·-·-·.

unaffected side of patients is also demonstrating different movement patterns to healthy participants.

Compared to healthy shoulders, mastectomy patients demonstrated increased activity in both the left and right affected shoulders in all the measured muscles (PM $p < 0.001$ CI[8.77–3.66];UT $p < 0.001$ CI[22.97–14.30]; Rhom $p < 0.001$ CI[15.38–12.07];SA $p < 0.001$ CI[10.36–5.48]). Whereas in the case of WLE patients such increases were not observed in SA and PM activity on the right affected shoulders, where a decrease was noted.

## DISCUSSION

This article reports movement deviation patterns in women following surgery for breast cancer that are similar to those seen in other known shoulder conditions. Left affected shoulders demonstrated the greatest degree of internal rotation of all shoulders studied (affected, unaffected and healthy). The difference between the left affected and the right unaffected shoulders with regards to internal rotation was greater than 10°, particularly during the critical zone. The importance of the difference in scapular external rotation between shoulders should not be underestimated. The difference observed in patients in this study is twice the difference observed between patients with impingement and healthy controls by Ludewig and Cook 2000. Reduced external rotation of the scapula has been attributed to cause external impingement of the shoulder due to its effect in decreasing subacromial space, where the subacromial bursa and rotator cuff tendons may be compressed (Michener et al., 2003). Furthermore, increased internal rotation of the scapula may force the glenohumeral joint into more external rotation, which has been associated with internal impingement of the posterior part of the rotator cuff (Solem-Bertoft et al., 1993). Whilst right affected shoulders showed greater external rotation than the left unaffected side, they still showed less external rotation than the optimum when compared to healthy right shoulders. This may explain the presence of symptoms in the right shoulder, albeit of a lesser magnitude than those experienced when the left side is affected.

Similarly, left affected shoulders showed a reduction in posterior tilt during lowering of the arm with the greatest difference seen in the critical zone. In contrast, right affected shoulders only showed a decrease in posterior tilt in the first 60° of humeral elevation. As with external rotation, a decrease in posterior tilt of the scapula has been noted as a causative factor for shoulder external impingment due to its

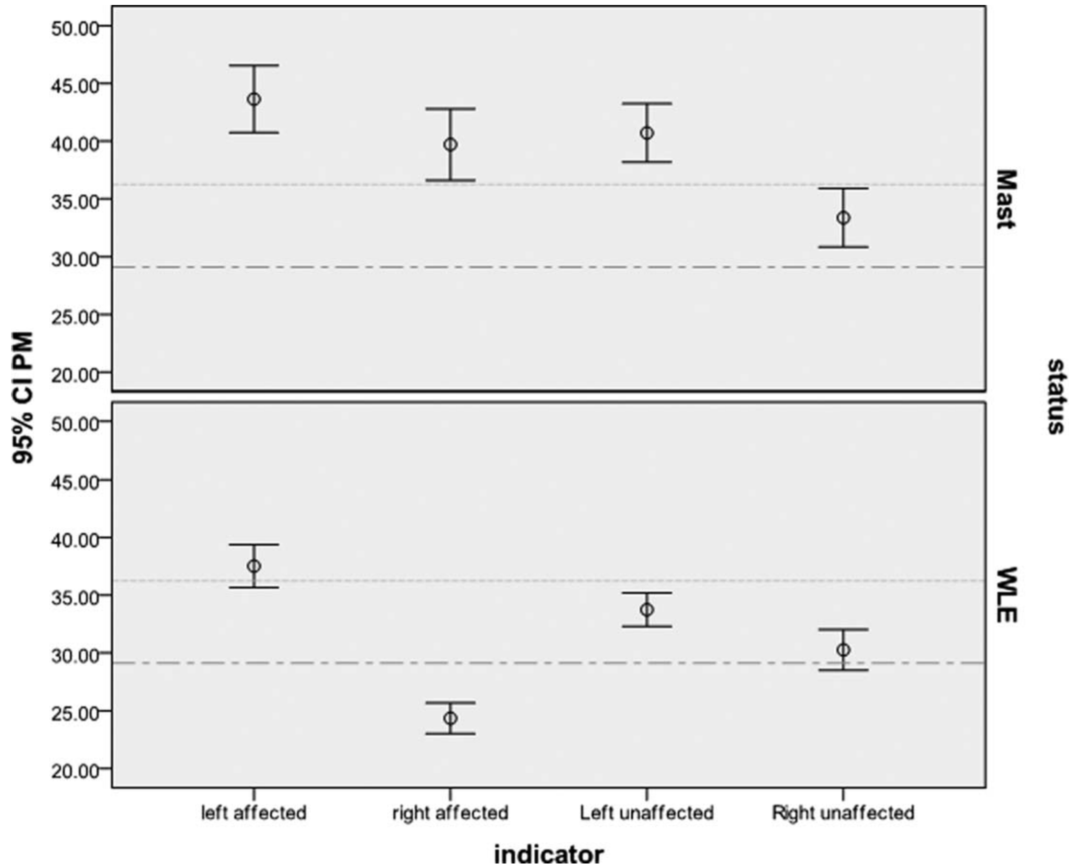


**Fig. 7**. EMG activity in Pectoralis Major for healthy participants and patients (Mean and SD). Key: Right healthy PM = ·········· and Left healthy PM = -·-·-·-·-·-·-·-·.

narrowing effect at the subacromial space (Seitz et al., 2011). Both affected sides are therefore presenting with movement deviation that places the patient at risk of developing recognized clinical conditions.

All affected shoulders demonstrated dysfunctional activity of the key muscles involved in the stability and fine movement of the scapula. Our study supports previous research in demonstrating the dysfunctional effect of the more aggressive mastectomy procedure (Crosbie et al., 2010; Sugden et al., 1998). In patients following a mastectomy, all assessed muscles demonstrated increased activity. It is possible that this may be a reflection of the increased muscle activity required for patients to mobilize shoulders with greater loss of tissue extensibility, and scarring. Furthermore, it is also plausible that this increased muscle activity may in itself be a cause of myogenic pain, and therefore patients' symptoms.

Left side affected WLE and/or mastectomy patients should be considered as high risk patients for developing shoulder complications after treatment. We and others have reported a strong association between observed movement deviations, muscle control, patient reported pain, chemotherapy and radiotherapy (Shamley et al., 2007, 2009, 2012). This raises the possibility that the observed adverse effects are latent effects of adjuvant therapies, which in most cancers undergo long term follow-up but appear to be neglected with respect to the development of shoulder complications in this population group.

Measuring patients before surgery was beyond the scope of this study. Presurgical measurement of patients might have allowed a better understanding of the effects of breast cancer surgery on shoulder kinematics and shoulder function. Although in comparison to fine wire EMG, SEMG may be affected by cross-talk, variability of adipose tissue in patients, and movement of skin over the underlying muscle, SEMG has been widely used for studying muscle activity of the shoulder (Wickham et al., 2010).

Shoulder morbidity has been reported in the literature for many years and the body of evidence is vast. Furthermore, we know that both movement deviations and patient's reports of pain improve with exercise regimes (McNeely et al., 2010). Yet in spite of this evidence there remains a dearth of dedicated rehabilitation services in many institutions. Neglecting to integrate rehabilitation, and long term follow up of the upper limb, in an oncology treatment pathway, means that shoulder conditions are lost to alternate treatment pathways where the link with treatment for

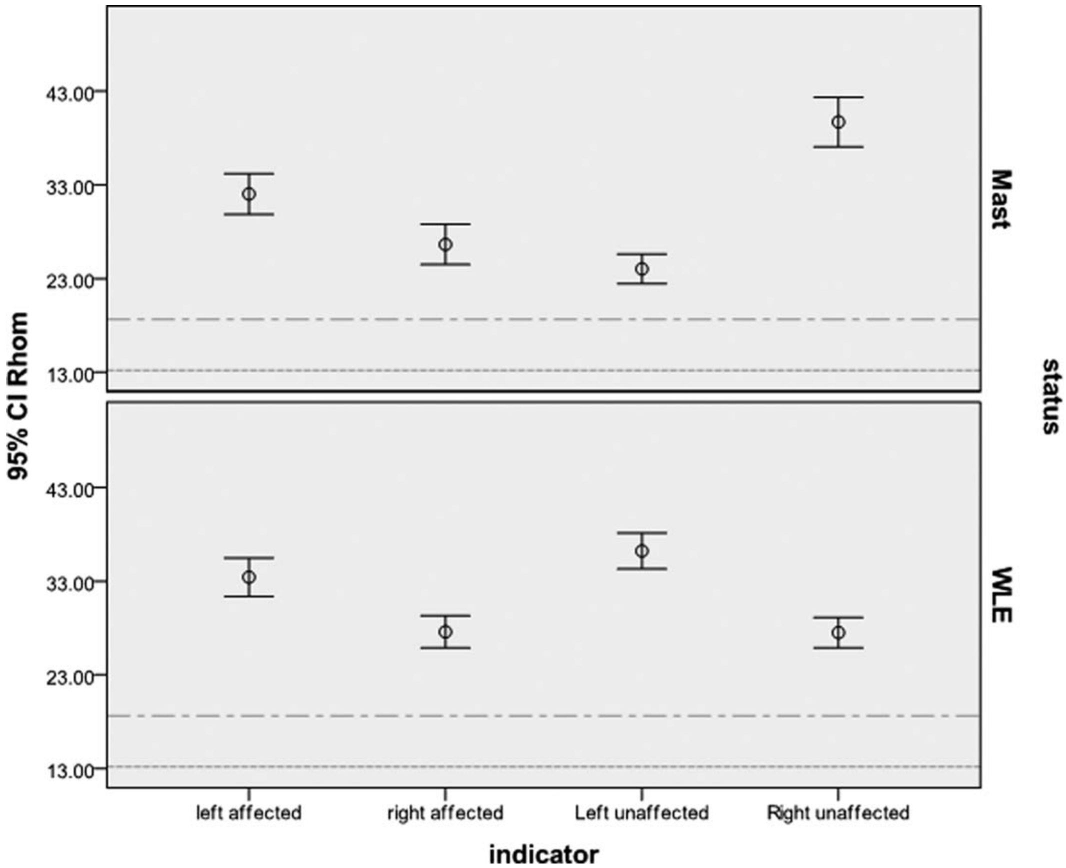


**Fig. 8**. EMG activity in Rhomboid Major for healthy participants and patients (Mean and SD). Key: Right healthy Rhom = ········· and Left healthy Rhom = -·-·-·-·-·-·.

breast cancer is not made. This is likely to be contributing to poor outcomes for the patient and more costly management of a chronic condition.

To balance patient need and low resources we have developed a surveillance system which incorporates an online risk-based "early warning" questionnaire, patient self-referral, and a targeted clinical response. The details of this system are currently being prepared for publication.

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