Effects of Mastectomy on Shoulder and Spinal Kinematics During Bilateral Upper-Limb Movement

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Background. Shoulder movement impairment is a commonly reported consequence of surgery for breast cancer.

Objective. The aim of this study was to determine whether shoulder girdle kinematics, including those of the scapula, spine, and upper limb, in women who have undergone a unilateral mastectomy for breast cancer are different from those demonstrated by an age-matched control group.

Design. An observational study using 3-dimensional kinematic analysis was performed.

Methods. Women who had a unilateral mastectomy on their dominant-arm side (n=29, mean [±SD] age=62.4±8.9 years) or nondominant-arm side (n=24, mean [±SD] age=59.8±9.9 years), as well as a control group of age-matched women without upper-limb, shoulder, or spinal problems (n=22, mean [±SD] age=58.1±11.5 years), were measured while performing bilateral arm movements in the sagittal, scapular, and coronal planes. All of the women were free of shoulder pain at the time of testing. Data were collected from the glenohumeral joint, the scapulothoracic articulation, and the spine (upper and lower thoracic and lumbar regions) using an electromagnetic tracking system.

Results. Women following mastectomy displayed altered patterns of scapular rotation compared with controls in all planes of movement. In particular, the scapula on the mastectomy side rotated upward to a markedly greater extent than that on the nonmastectomy side, and women following mastectomy displayed greater scapular excursion than controls.

Conclusions. The findings suggest that altered motor patterns of the scapula are associated with mastectomy on the same side. Whether these changes are harmful or not is unclear. Investigation of interventions designed to restore normal scapulo-humeral relationships on the affected side following unilateral mastectomy for breast cancer is warranted.
Kinematics During Arm Elevation Following Mastectomy

Following mastectomy for breast cancer, many women experience impairment in shoulder movements that can substantially affect their everyday function and quality of life. Although some symptoms, such as arm swelling due to lymphedema, are easily accounted for, other symptoms, such as chronic ache and pain, which women report in the shoulder and upper trunk months to years after surgery, are not always associated with their physical strength (force-generating capacity) or range of motion at the shoulder. The lack of a relationship between impairments and self-reported function suggests that other factors are likely to contribute to these persisting problems.

The residual effects of surgical scarring and fibrosis following radiotherapy could affect the mechanics of the shoulder region through tethering of soft tissue or pain-inhibited movement. The incidence of shoulder morbidity has been found to be significantly and substantially higher in women treated with postsurgical radiotherapy (17%) compared with a group of women who received no radiotherapy (2%). Additionally, women who undergo mastectomy are almost 6 times more likely to experience shoulder restriction and impairment than patients who undergo breast-conserving surgery, and, despite improved surgical techniques and postoperative care, pain and functional limitation continue to pose problems.

The residual effects of surgery or radiotherapy also may affect the intricate shoulder girdle movements required for arm elevation. Normally, the humerus moves smoothly and in synchrony with respect to the scapula. This scapulohumeral rhythm is achieved through precise muscle firing of scapulothoracic and scapulohumeral musculature in response to complex proprioceptive information, maintaining the head of the humerus within the glenoid fossa throughout the movement. The asymmetry of both soft tissue motility and mass distribution across the chest wall that arises from loss of a breast potentially could affect upper-limb movements and contribute to trunk or arm symptoms. Previous research has identified that there can be changes in the size and activation of muscles around the upper trunk consequential to surgery for breast cancer, and soft tissue contracture may result from protective posture and movement. A recent study showed significant changes during unilateral arm elevation in scapular kinematics on the operated side following surgery for breast cancer. In that study, however, the sample included women who had undergone mastectomy with or without radiotherapy, wide local excision with or without radiotherapy, or chemotherapy. In addition, participants included women with coexisting shoulder pain on the side of surgery.

An important confounder in understanding the mechanism underlying long-term shoulder pain in women following mastectomy is the relatively high incidence of idiopathic or posttraumatic shoulder disability that occurs in the same age group. Seventy percent of people with adhesive capsulitis are women, and the point prevalence of shoulder pain has been reported from large population surveys as affecting 8.2% or more of the population aged 45 to 54 years, rising to 13.2% for those aged 75 to 84 years. Sixty-five percent of women diagnosed with breast cancer are between 40 and 70 years of age. Thus, in exploring the kinematics of the shoulder complex in women following mastectomy, it is important to ensure that disturbances cannot be attributed to coexisting joint pathology.

Our aim in this observational study was to determine whether glenohumeral, scapular, and spinal kinematics in women who had undergone a mastectomy, but who were asymptomatic with respect to shoulder pain, were different from those demonstrated by a control group. If there was a significant difference in the inherent movement patterns of the upper limb and trunk displayed by the women following mastectomy, this difference in movement patterns might be a source of potential impairment. Such subtle disturbances previously have been associated with shoulder tightness and idiopathic loss of shoulder range of motion.

Single-arm elevation inevitably is associated with other movements designed to maintain postural equilibrium, as well as being synergetic to the primary motion. We wanted to ensure that the movements demonstrated were limited to those required to achieve arm elevation. Therefore, in this study, we tested simultaneous, bilateral arm motion in 3 different planes of movement: sagittal (forward flexion), coronal (abduction), and scapular (approximately 30° forward from abduction). We compared participants’ performance with that of an age-matched
control group. In particular, we sought insights into the effect of the mastectomy on intralimb kinematics.

**Method**

**Participants**

Fifty-three women, aged between 44 and 84 years, who had undergone a unilateral mastectomy at least 12 months previously, did not have lymphedema, and had no recent history of disorders affecting the upper limb or spine were recruited via newspaper advertisement. Within this cohort, 29 participants had undergone surgery on their dominant side (mastectomy dominant-side group), and 24 participants had undergone surgery on their nondominant side (mastectomy nondominant-side group). We also recruited an age-matched (43–80 years) control group of women (n=22) who also had no upper-limb, shoulder, or spinal problems. Sample group sizes were determined from data previously reported for a similar activity and were based on the power (80%) required to detect a difference of 3 degrees in scapular upward rotation, which we determined as clinically significant. The target sample size was 22 participants in each group; however, convenience sampling provided slightly larger and less numerically balanced cohorts in the 2 mastectomy groups.

We assessed the participants’ activity levels using the International Physical Activity Questionnaire (IPAQ) (1–3 scale) and their quality of life using the Medical Outcomes Study 36-Item Short-Form Health Survey questionnaire (SF-36) (0–100 scale). We also assessed shoulder impairment with the Disabilities of the Arm, Shoulder, and Hand questionnaire (DASH), which has a maximum score of 100, indicating maximum disability. We collected and recorded general anthropometric and demographic data. All participants gave informed consent.

**Inclusion and Exclusion Criteria**

As simple screening instruments, we measured overall shoulder forward flexion range of motion using a digital inclinometer and shoulder flexor strength at 90 degrees of flexion using a handheld dynamometer. Any participant who was unable to achieve at least 150 degrees of sagittal-plane humeral elevation or who demonstrated asymmetrical weakness of the shoulder flexors, notionally defined as one side producing a maximum force of ≤80% of the other side, was excluded from the study.

We established the presence of shoulder impingement (a common manifestation of dysfunctional shoulder motor control) using the dichotomous Hawkins-Kennedy and dynamic impingement tests. The Hawkins-Kennedy test, although widely used, is primarily a passive test of impingement, whereas the dynamic impingement test assesses impingement in the shoulder during dynamic active motion. Individuals who demonstrated a positive result on either test were excluded, as were those who reported any existing or recent (previous 6 months) pain in the shoulder region, either at rest or during activity, or any history of surgery (apart from the mastectomy in the relevant groups) to the shoulder region.

We determined the presence of lymphedema using single-frequency bioimpedance (Z) analysis. Participants were excluded on the presence of clinically significant lymphedema, as determined by the ratio: $Z_{\text{unaffected limb}}/Z_{\text{affected limb}}$. A ratio of less than 1.139 on the dominant side or 1.066 on the nondominant side indicates absence of lymphedema.

**Protocol**

The women were required, while seated on a backless stool with both feet on the ground, to raise both their arms with elbows extended simultaneously as far overhead as they could. Seating the participants ensured that the movements were localized to the upper limbs and trunk, rather than permitting the lower limbs to contribute to the activity.

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**The Bottom Line**

**What do we already know about this topic?**

It is logical that, following mastectomy for breast cancer, movement of the shoulder region on the operated side can be compromised. The extent and nature of alterations in shoulder kinematics are not known.

**What new information does this study offer?**

After mastectomy, patterns of scapular movement are altered, particularly on the operated side, despite the absence of mechanical restriction. This suggests that there may be changes to the motor patterns of the scapula, perhaps as a learned behavior.

**If you’re a patient, what might these findings mean for you?**

Closer attention to the restoration of more “normal” scapulohumeral rhythm may be warranted in the recovery period following mastectomy.
The order in which movements were completed was forward flexion, abduction, and movement in the scapular plane. For each movement, the women completed 3 repetitions. The movement commenced with the arm at the side, thumb pointing anteriorly, and this position was maintained throughout the movement. One cycle of movement took approximately 3 seconds.

To collect kinematic data, we used a multi-sensor, 6-degree-of-freedom electromagnetic tracking device (Motion Star Wireless 2 system with an extended range transmitter).* Sensors were firmly attached on the skin overlying the superior acromial processes, first and sixth thoracic and first lumbar vertebral spinous processes, and the second sacral segment. The humeral sensors were attached to the skin on the lateral side of the arm below the deltoid muscle insertion. A ninth sensor, attached to a pointer, was used to manually digitize anatomical landmarks in the upper limbs, scapulae, and trunk. Calibration of the body segments adhered to a previously reported protocol.25 Following digitization and calibration, we collected kinematic data at 100 Hz. This protocol has been reported to have good in vivo reliability, with an intraclass correlation coefficient value of .91 for position and an accuracy of 1.2 degrees.25 Based on these data, standard error of measurement (SEM) values were calculated for each of the kinematic variables of interest following the approach described by Palombo et al.32 Minimal detectable change (MDC) was computed as 1.96 × SEM and represents the 95% confidence interval for the SEM. Data processing and reduction were carried out using conventional biomechanical analysis by a researcher who was blinded to the group allocation of participants.

The joint angle values obtained in the neutral posture were subtracted from the data for each participant, resulting in a starting position close to zero for each movement. Thus, movements are reported relative to the starting posture and are not absolute with respect to global or local coordinate systems. Each participant was instructed to rest with her arm hanging as close to vertical as possible. The starting positions were analyzed between groups and planes of motion to ensure that the movement patterns were not distorted by different offsets in any group or plane of motion.

The kinematic data of interest were those of the humeral, scapulothoracic, and spinal joints. For the purpose of this analysis, humeral motion was defined with respect to the global vertical axis (humeral elevation). The 3 scapulothoracic movements assessed were upward/downward rotation, internal/external rotation, and anterior/posterior tilt (rotation about the longitudinal axis of the spine of the scapula) (Fig. 1). We subdivided the trunk into upper (T1–T6) and lower (T7–T12) thoracic and lumbar (L1–L5) regions using the spinous processes of relevant vertebrae as landmarks and recorded flexion and extension and lateral flexion and axial rotation motions of each spinal region. Upper and lower thoracic regions, defined here according to convenience, have been shown to behave differently from one another,33–35 probably because the upper segment is more closely tethered through the more rigid anterior articulation of the ribs with the sternum. Although the participants exhibited humeral elevation in excess of 90 degrees, particularly within the sagittal plane, we confined the analysis of scapular and thoracic movements to positions associated with 4 defined angles of humeral elevation in each movement plane: 0, 30, 60, and 90 degrees. The average values of the scapular and thoracic postures from the 3 repetitions at each of the noted angles were used for analysis.

Data Analysis

The primary focus of the investigation was to determine whether mastectomy affected scapular and thoracic kinematics during elevation of the arm. In particular, we were curious to establish whether asymmetry of scapular motion, notably upward rotation, as has been reported in women who had not undergone a mastectomy,25 was different in women following mastectomy. We also were interested in determining whether the scapular and spinal contributions to overall humeral elevation were incrementally and linearly related to the plane in which motion occurred and to the angle of humeral elevation.

For the purpose of this study, we tested the primary hypotheses that there would be no difference: (1) among groups for 3-dimensional (3D) scapular and spinal contributions to overall movement at any of the designated humeral angles, (2) among the patterns of scapular and spinal motion in any of the 3 planes of motion, or (3) between dominant- and nondominant-arm sides with respect to 3D scapular motion.

Statistical analysis was carried out using PASW version 17 software.† A full factorial 3 × 4 × 3 × 2 repeated-measures analysis of variance (ANOVA) with planned contrasts was used to separately investigate scapular internal rotation, upward rotation, and anterior tilting on each of the dominant and nondominant...
sides. The between-group factor was group (mastectomy dominant-side, mastectomy nondominant-side, and control), and the within-group factors were humeral elevation angle (0°, 30°, 60°, and 90°), plane of motion (sagittal, scapular, and coronal), and side (dominant and nondominant). Plane of motion was an important component of the analysis and was tested to establish whether the changes in scapular pattern were systematic and progressive with changing plane of humeral elevation. Repeated-measures contrasts were polynomial for plane and angle and difference for groups, which were treated in a pair-wise fashion. Body mass index (BMI) was included as a continuous covariate in all linear models, as we had determined that women in the control group had BMI values that were significantly lower than those in the mastectomy groups ($F_{2,72} = 6.20; P = .003$), although there was no significant difference between the 2 mastectomy groups ($P = .916$).

A repeated-measures ANOVA also was used to investigate the relationships between spinal segment movements and arm elevation. For the purposes of this analysis, because arm motion was bilateral, lateral flexion and axial rotation of the spine would not be expected to occur to a significant extent. To investigate these out-of-plane movements, we calculated the summated root mean square value for lateral flexion and axial rotation for each participant at each discrete glenohumeral angle and in each plane and used this resultant as a single variable of convenience. Flexion and extension were recorded as a single variable at each interval in each test. Sphericity was tested in all cases using the Mauchley procedure, and the Greenhouse-Geisser correction was applied in all cases where sphericity was found to be significant.

A one-way ANOVA was used to determine whether any differences existed among groups for entry data such as age, available range of motion, and so on. Post hoc analysis used the Tukey test for pair-wise comparison of variables when significant differences were observed among groups. Interactions found to be significant ($P < .05$) are identified, but nonsignificant interactions are not reported.

**Effect of Radiotherapy on Arm Elevation**

Half of the women in the mastectomy nondominant-side group had received radiotherapy as part of their...
postoperative management, enabling an opportunistic secondary analysis to determine its effect on elevation of the arm. For each of the analyses described above, a secondary analysis was undertaken in which the between-group factor was replaced by whether or not the woman had received radiotherapy.

Results
Participant Characteristics
The participant characteristics are shown in Table 1. There was no significant difference in age among the groups \( \left( F_{2.72} = 1.22; P = .301 \right) \). Apart from BMI, as previously noted, there were no significant differences among the groups for any of the general participant characteristics.

Kinematic Variables
Data for all 3D scapular angular measurements, corresponding to the values at the predetermined humeral elevation angles, are presented in eTables 1, 2, and 3 (available at ptjournal.apta.org). Patterns of scapular rotations are illustrated in Figures 2, 3, and 4. Data for associated spinal motion are presented in eTable 4 (available at ptjournal.apta.org). Because average lumbar spine motion was less than 1 degree and, therefore, neither clinically important nor probably greater than measurement error, no further analysis will be reported. The SEM values for scapular rotations and thoracic flexion were determined and are indicated in each relevant table, along with calculated values for MDC. No significant differences were found among starting positions for the glenohumeral joint (with respect to the global coordinate system) for groups or planes of motion \( \left( F_{4.144} = 0.77; P = .549 \right) \).

Group Effects
Significant effects were detected among groups, particularly for scapular upward rotation during humeral elevation in both the scapular and coronal planes (Tab. 2) and on both dominant and nondominant sides. In general, women in both mastectomy groups demonstrated significantly more upward rotation on both sides than did the control group. On the dominant side, both mastectomy groups demonstrated greater upward/downward rotation compared with the control group, but the 2 mastectomy groups did not differ significantly from one another. Upward/downward rotation on the nondominant side, however, also was significantly greater in the mastectomy nondominant-side group than in the mastectomy dominant-side group \( \left( P = .036 \right) \). The magnitudes of all of these significant differ-
Figure 2. Patterns of scapular internal rotation on the dominant and nondominant sides for the 3 groups during humeral elevation in the (A) sagittal plane, (B) scapular plane, and (C) coronal plane. Mean and 95% confidence interval values for each group are illustrated. Solid circles represent the values for the control group at the 4 humeral angles (0°, 30°, 60°, and 90°); open squares represent values for the mastectomy dominant-side group, and filled diamonds represent values for the mastectomy nondominant-side group. Values are deliberately offset (by ±2°) among groups for ease of representation. * = P < .05.
Figure 3.
Patterns of scapular upward rotation on the dominant and nondominant sides during humeral elevation in the (A) sagittal plane, (B) scapular plane, and (C) coronal plane. Symbols are as defined for Figure 2. * = p < .05, ** = p < .001.
Figure 4.
Patterns of scapular anterior tilt on the dominant and nondominant sides during humeral elevation in the (A) sagittal plane, (B) scapular plane, and (C) coronal plane. Symbols are as defined for Figure 2.
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Table 2.
Group Effects for Scapular and Thoracic Motion During Humeral Elevation in 3 Planes

| Motion                        | Side                  | Sagittal | Scapular | Coronal                  |
|-------------------------------|-----------------------|----------|----------|--------------------------|
| Scapular internal rotation    | Dominant F₂,₇₂ = 0.52; P = .6 | F₂,₇₂ = 0.10; P = .902 | F₂,₇₂ = 0.07; P = .93 |
|                               | Nondominant F₂,₇₂ = 2.08; P = .112 | F₂,₇₂ = 0.62; P = .538 | F₂,₇₂ = 5.27; P = .007 |
| Scapular upward rotation      | Dominant F₂,₇₂ = 2.90; P = .062 | F₂,₇₂ = 8.41; P = .001 | F₂,₇₂ = 14.45; P < .001 |
|                               | Nondominant F₂,₇₂ = 2.31; P = .107 | F₂,₇₂ = 11.92; P < .001 | F₂,₇₂ = 25.65; P < .001 |
| Scapular anterior tilt        | Dominant F₂,₇₂ = 0.82; P = .444 | F₂,₇₂ = 0.84; P = .435 | F₂,₇₂ = 2.74; P = .071 |
|                               | Nondominant F₂,₇₂ = 0.44; P = .643 | F₂,₇₂ = 0.74; P = .481 | F₂,₇₂ = 0.41; P = .668 |
| Upper thoracic flexion        | F₂,₇₂ = 3.92; P = .047 | F₂,₇₂ = 1.36; P = .262 | F₂,₇₂ = 4.69; P = .012 |
| Lower thoracic flexion        | F₂,₇₂ = 1.15; P = .322 | F₂,₇₂ = 1.46; P = .239 | F₂,₇₂ = 1.64; P = .201 |
| Out-of-plane motion           | F₂,₇₂ = 0.19; P = .828 | F₂,₇₂ = 1.19; P = .309 | F₂,₇₂ = 0.48; P = .621 |

ences were in excess of 3 times the MDC (eTab. 2, available at ptjournal.apta.org).

There was one significant difference noted for scapular internal/external rotation during humeral elevation in the coronal plane, with the mastectomy nondominant-side group demonstrating significantly more external rotation on the nondominant side than the control group (P = .006). Anterior tilt of the scapula did not demonstrate any significant effects for group in any plane of elevation.

Upper thoracic flexion was significantly greater in the mastectomy dominant-side group than in the control group during humeral elevation in the sagittal plane (P = .05) and also greater than in the mastectomy nondominant-side group during humeral elevation in the coronal plane (P = .01). However, the amplitudes of these differences were marginal and less than the 3 degrees defined as clinically important. No significant group differences were detected for either lower thoracic flexion or out-of-plane movements. Body mass index was not found to produce a significant effect in any comparison.

**Effect of Plane of Humeral Elevation**
Significant effects were detected for changes to scapular motion as humeral elevation progressed from the sagittal plane through the scapular plane to the coronal plane. Scapular internal/external rotation was positive and linear in the sagittal plane, but became progressively more negative in association with the changing elevation plane. In addition, the scapular response became significantly more quadratic in pattern (P = .024); that is, maximum external rotation occurred around 60 degrees of humeral elevation, and then the scapula began to rotate internally once more (Fig. 2C).

Upward/downward rotation was consistently linear across the discrete elevation angles and increased significantly from sagittal- to scapular- and coronal-plane motion (F₂,₇₂ = 4.32; P = .017). There was no
significant difference between scapular- and coronal-plane motion trends ($P=.388$). There were no significant linear or quadratic effects of changing the plane of humeral elevation on overall anterior tilt of the scapula ($P=.65$).

Upper thoracic flexion became progressively greater as humeral elevation progressed from the sagittal plane to the coronal plane. This progression involved a significant quadratic trend ($F_{1,72}=8.51; P=.005$); however, the magnitude of the difference did not substantially exceed MDC values. The lower thoracic region progressively and significantly extended in response to plane of motion. There was a significant linear increase in the spinal component as the humeral elevation moved from the sagittal plane to the coronal plane ($F_{1,72}=42.3; P<.001$). The amplitude of the difference was more than 4 degrees, which was 10 times MDC values.

Out-of-plane movements increased in a cubic trend, with progressive change in humeral plane ($F_{1,72}=9.39; P=.003$); however, the amplitude of this change was less than could be considered clinically important.

**Effect of Side**

Significant effects were found between dominant- and nondominant-side scapular motions during humeral elevation. The control group demonstrated significantly greater upward/downward rotation in both the scapular plane ($P=.048$) and the coronal plane ($P=.043$) but no other asymmetries. Women whose surgery affected their dominant side were significantly asymmetrical with respect to internal/external rotation in the sagittal plane ($P=.004$) and anterior/posterior tilt in the coronal plane ($P=.049$) but otherwise did not demonstrate significant side-related differences.

The group of women whose mastectomy affected their nondominant side demonstrated significantly more scapular upward rotation on the affected side in the sagittal ($P=.003$), scapular ($P=.001$), and coronal ($P<.001$) planes. They also had more nondominant-side scapular external rotation ($P=.012$) and significantly less posterior tilt of the nondominant scapula ($P=.003$) during humeral elevation in the coronal plane. In all cases, these statistically significant differences exceeded MDC values.

**Effect of Radiotherapy**

There were no significant differences for any scapular motion in any plane of glenohumeral elevation between the radiotherapy and nonradiotherapy subgroups of the mastectomy nondominant-side group. Equally, there were no statistically significant differences between the radiotherapy and nonradiotherapy subgroups for upper thoracic, lower thoracic, lumbar, or out-of-plane movements.

**Discussion**

We investigated the effect of mastectomy on upper-quadrant movement in women who reported no significant upper-limb or spinal symptoms, testing bilateral arm elevation in 3 planes of movement. The deliberate selection of participants who were no longer considered to be in the recovery phase after surgery and who had stable clinical presentations was designed to identify intrinsic changes in the kinematics of the shoulder girdle and upper trunk that might be ascribed to the consequences of their surgery and postoperative activity rather than to shoulder pathology that might have originated from surgery or from other causes. Although the women in the mastectomy groups reported slightly higher scores for DASH and lower scores for SF-36 assessments compared with the control group, the absolute values (relative to the total ranges for the instruments) were small, and there was no significant association between any of the kinematic variables and these self-report variables. Similarly, the fact that the women in the mastectomy groups were more overweight compared with the control group did not appear to exert any influence on the outcomes of the study. The testing of individuals who were symptom-free meant that we anticipated subtle rather than obvious differences from control group.

The results of our investigation indicate the rejection of all 3 of our primary hypotheses. There were significant differences among groups for the scapular and upper thoracic spine movements during humeral elevation, although the discrepancy was almost entirely limited to upward rotation of the scapula, which demonstrated systematic differences from the control group. The magnitude of the differences in upward rotation was substantially greater than the calculated error terms for the movements in question. Although there were spinal movements associated with the upper-extremity elevation trials, similar to patterns previously reported, the differences among the groups were small and did not indicate clinically meaningful changes. Women who had undergone a mastectomy demonstrated significant changes to the association between scapular upward rotation and glenohumeral motion compared with the women in the control group. Specifically, women who had undergone a mastectomy had a greater scapular contribution to the overall motion, particularly on the affected side. Although it has been reported that asymmetries in scapular motion occur naturally in individuals who are healthy, with the nondominant side tending to rotate upward more than the dominant side, a finding supported in this cohort with 13% greater upward ro-
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tation on the nondominant side at 90 degrees of humeral elevation in the coronal plane, the mastectomy nondominant-side group demonstrated a greater degree of asymmetry (29%) than the control group. Interestingly, the mastectomy dominant-side group demonstrated 14% more scapular upward rotation on their dominant, mastectomy side.

Differences recently have been reported in side-to-side movement of the scapula during unilateral arm elevation in the plane of the scapula in women following breast cancer surgery. The researchers found in women following breast cancer surgery, the scapula during unilateral arm elevation in side-to-side movement of their dominant, mastectomy side. Interestingly, the mastectomy dominant-side group demonstrated 14% more scapular upward rotation compared with the other groups, although an identical pattern on the nondominant side. Why the women in the mastectomy dominant-side group did not show a similar distortion on the affected side is not immediately apparent.

Scapular and thoracic participation in upper-limb motion is a natural component of the kinematics of the shoulder girdle, and it frequently is altered in people with problems affecting the shoulder region. In our study, however, none of the women reported current shoulder symptoms, nor did they demonstrate positive shoulder impingement patterns. They had no significant difference in the range of shoulder elevation and, from the kinematics of the scapula recorded in the study, had no apparent limitation of scapular motion.

We speculate that the reason for this altered scapular contribution may be a motor control adaptation arising from reduced frequency and amplitude of elevations of the arm following surgery and during everyday activities. The changes to scapulohumeral motion apparently were not attributable to actual shoulder pathology; therefore, the alteration is likely to arise through adaptive changes to motor patterns and learned usage.

One explanation as to why the postmastectomy groups used adaptive strategies may be related to postoperative surgical management. Typically, a drain is inserted in the incision on the chest wall to enable drainage of any seroma. Women are encouraged not to elevate their arm above their head in the early postoperative period, as it can cause formation or production of serous fluid. Furthermore, even after drain removal, women are instructed to protect their affected limb to prevent lymphedema. The adaptive changes may simply be a consequence of fewer elevations of the arm past 90 degrees. An observational study of older participants who were healthy determined that their arm moved beyond this position 13 times per hour, which suggests that such movement may be necessary to maintain range and synchrony of movement.

There is no clear causal evidence that altered scapular kinematics will lead to further shoulder impairment. The increased scapular upward rotation in particular, although consistent and quite dramatic on the operated side of those women in the postmastectomy groups, is not a symptom of shoulder dysfunction. In fact, evidence in the literature is divided regarding whether upward scapular rotation is implicated in symptomatic shoulder problems. Scapular upward rotation has been reported to be increased in people with adhesive capsulitis and in people with idiopathic shoulder restriction, reduced in people with multidirectional shoulder instability, and either reduced or not clearly differentiated in people with shoulder impingement. Nevertheless, significant changes in the kinematic patterns around the shoulder are worthy of notice and might be symptomatic of some mechanical anomaly, in the same way that a painless limp may indicate a mechanical gait dysfunction.

Our postulation regarding “guarding” of the operated arm requires systematic investigation and warrants a prospective trial in which the unaffected arm is constrained.
and the arm on the operated side is used for most actions to determine whether shoulder kinematics could be maintained or restored to normal in the affected arm of women after mastectomy. Equally, it would be important to determine whether the same scapular kinematics are associated with the development of shoulder pain and impairment in women following mastectomy. From such an investigation, it might be possible to determine whether the altered kinematics we have observed are common to both people who are asymptomatic and those who are symptomatic.

It has been suggested that the effects of radiotherapy are implicated in the alterations to upper-limb movement patterns. The finding that there were no significant differences for any of the scapular or thoracic movements in the women who had received radiotherapy following surgery compared with those who had not received radiotherapy was of some interest. The number of women who received radiotherapy in the mastectomy dominant-side group (n = 6) was too small to draw clear inferences; however, the mastectomy nondominant-side group was evenly balanced between those who had and those who had not received radiotherapy. The lack of any substantial or significant differences in range of movement tends to contradict the suggestion that radiotherapy is a major cause of shoulder girdle dyskinesia. This finding tends to support the views of Lee and colleagues, who concluded that any alteration in the compliance of irradiated tissue was not a major factor in determining shoulder symptoms. Furthermore, if there is scarring or alteration in the compliance of the chest wall following radiotherapy, it did not appear to be influential in the altered scapular kinematics demonstrated in this study.

Conclusions
The findings of this study indicate complex kinematic distortions, particularly during abduction in the coronal plane, in which the relationships between scapular and glenohumeral movements are changed. Of note is the fact that the population studied did not report shoulder symptoms. It is not known whether these small discontinuities and changes to the associations of scapular and humeral motion are prognostic of shoulder impingement or future development of symptoms. Previous interventions, administered at an early stage, have shown the benefits of physical therapy and patient education on recovery of shoulder mobility, but in that study the emphasis was on acute phase recovery of range of motion, rather than the development of skill, symmetry, and coordination. It would be interesting to investigate the early use of motor control techniques for the re-establishment of normal scapulo-humeral coordination and whether they are associated with altering the incidence of shoulder symptoms following mastectomy. Furthermore, because this study placed no extra demand—in the form of load resistance—on the women during movement, it would be valuable to repeat the experiment with a controlled resistive load to the movement to ascertain whether there are other kinematic changes that appear only in response to increased muscle activity.

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References
1 Vooget AC, Ververs JM, Vingerhoets AJ, et al. Lymphoedema and reduced shoulder function as indicators of quality of life after axillary lymph node dissection for invasive breast cancer. Br J Surg. 2003;90:76–81.
2 Erickson VS, Pearson ML, Ganz PA, et al. Arm edema in breast cancer patients. J Natl Cancer Inst. 2001;93:96–111.
3 Atken DR, Monton JP. Complications associated with mastectomy. Surg Clin North Am. 1983;63:1351–1352.
4 Chiverton SG, Perry PM. Morbidity after surgery for breast cancer. Br J Surg. 1987;74:1166.
5 Haid A, Köberle-Wührer R, Knauer M, et al. Morbidity of breast cancer patients following complete axillary dissection or sentinel node biopsy only: a comparative evaluation. Breast Cancer Res Treat. 2002;73:31–36.
6 Al-Ghazal SK, Fallowfield L, Blamey RW. Comparison of psychological aspects and patient satisfaction following breast conserving surgery, simple mastectomy and breast reconstruction. Eur J Cancer. 2000;36:1938–1943.
7 Merchant CR, Chapman T, Kilbreath SL, et al. Decreased muscle strength following management of breast cancer. Disabil Rehabil. 2008;30:1098–1105.
8 Højris I, Andersen J, Overgaard M, Overgaard J. Late treatment-related morbidity in breast cancer patients randomized to pre-mastectomy radiotherapy and systemic treatment versus systemic treatment alone. Acta Oncol. 2000;39:355–372.
9 Sugden EM, Rezvani M, Harrison JM, Hughes LD. Shoulder movement after the treatment of early stage breast cancer. Clin Oncol (R Coll Radiol). 1998;10:173–181.
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10 Lauridsen MC, Torsleff KR, Husted H, Ericsson C. Physiotherapy treatment of late symptoms following surgical treatment of breast cancer. *Breast*. 2000;9:45–51.

11 Cheville AL, Tchou J. Barriers to rehabilitation following surgery for primary breast cancer. *J Surg Oncol*. 2007;95:409–418.

12 Inman VT, Saunders JBdeCM, Abbot LC. Observations on the function of the shoulder joint. *J Bone Joint Surg Am*. 1944;26:1–30.

13 McClure PW, Michener LA, Sennett BJ, Karduna AR. Direct 3-dimensional measurement of scapular kinematics during dynamic movements in vivo. *J Shoulder Elbow Surg*. 2001;10:269–277.

14 Belling Sørensen AK, Jorgensen U. Second-phase rehabilitation and associated muscle activity in people with symptoms of shoulder impingement. *Ann Rheum Dis*. 2002;61:115–120.

15 Warner JJ, Micheli LJ, Arsalanian LE, et al. Scapulothoracic motion in normal shoulders and shoulders with glenohumeral instability and impingement syndrome: a study using Moire topographic analysis. *Clin Orthop Relat Res*. 1992;285:191–199.

16 Shamley D, Srinaganathan R, Oskrochi R, et al. Three-dimensional scapulothoracic motion following treatment for breast cancer. *Breast Cancer Res Treat*. 2009;118:315–322.

17 Brue S, Valentin A, Forssblad M, et al. Idiopathic adhesive capsulitis of the shoulder: a review. *Knee Surg Sports Traumaol Arthrosc*. 2007;15:1048–1054.

18 Sheridan MA, Hannafin JA. Upper extremity: emphasis on frozen shoulder. *Orthop Clin North Am*. 2006;37:531–539.

19 Badley EM, Tennant A. Changing profile of Australian Institute of Health and Welfare. Available at: http://www.aihw.gov.au/2002;3:145–153.

20 Allander E. Prevalence incidence and remission rates of some common rheumatic diseases or syndromes. *Scand J Rheum*. 1974;3:145–153.

21 Australian Institute of Health and Welfare. Available at: http://www.aihw.gov.au/2006;9:356–371.

22 Cho OH, Yoo YS, Kim NC. Efficacy of comprehensive group rehabilitation for women with early breast cancer in South Korea. *Nurs Health Sci*. 2006;8:140–146.

23 Yang JL, Lu TW, Chou FC, et al. Secondary motions of the shoulder during arm elevation in patients with shoulder tightness. *J Electromyogr Kinesiol*. 2009;19:1035–1042.

24 Rundquist PJ. Alterations in scapular kinematics in subjects with idiopathic loss of shoulder range of motion. *J Orthop Sport Phys Ther*. 2007;37:19–25.

25 Crosbie J, Kilbreath SL, Hollmann L, York S. Scapulohumeral rhythm and associated spinal motion. *Clin Biomech(Bristol, Avon)*. 2008;23:184–192.

26 Craig CL, Marshall AL, Sjöstrom M, et al. International physical activity questionnaire: 12-country reliability and validity. *Med Sci Sports Exerc*. 2003;35:1381–1395.

27 Hudak PL, Amadio PC, Bombardier C, et al. The Upper Extremity Collaboration Group. Development of an upper extremity outcome measure: the DASH (Disabilities of the Arm, Shoulder, and Hand). *Am J Ind Med*. 1996;29:602–608.

28 Hawkins RJ, Kennedy JC. Impingement syndrome in athletics. *Am J Sports Med*. 1980;8:151–157.

29 Allingham C. The shoulder complex. In: Zuluaga M, Briggs C, Carlisle J, et al, eds. *Sports Physiotherapy: Applied Science and Practice*. Melbourne, Victoria, Australia: Churchill Livingstone; 1995:357–406.

30 Hayes S, Cornish B, Newman B. Comparison of methods to diagnose lymphedema among breast cancer survivors: 6-month follow-up. *Breast Cancer Res Treat*. 2005;89:221–226.

31 York SL, Ward LC, Czerniak S, et al. Single frequency versus bioimpedance spectroscopy for the assessment of lymphedema. *Breast Cancer Res Treat*. 2009;117:177–182.

32 Palombo RM, Craik RL, Mangione KK, Tomlinson JD. Determining meaningful changes in gait speed after hip fracture. *Phys Ther*. 2006;86:809–816.

33 Crosbie J, Vachalathiti R, Smith R. Patterns of spinal motion during walking. *Gait Posture*. 1997;5:6–12.

34 Edmondston SJ, Singer KP. Thoracic spine: anatomical and biomechanical considerations for manual therapy. *Man Ther*. 1997;2:132–143.

35 Theodoridis D, Ruston S. The effect of shoulder movements on thoracic spine 3D motion. *Clin Biomech (Bristol, Avon)*. 2002;17:418–421.

36 Biryukova E, Roby-Brami A, Frolov AA, Molchta M. Kinematics of human arm reconstructed from spatial tracking recordings. *J Biomech*. 2000;33:985–995.

37 Ludewig PM, Cook TM. Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. *Phys Ther*. 2000;80:276–291.

38 Harmer V. The surgical management of breast cancer. *Nurs Times*. 2000;96(48):54–55.

39 Schurr K, Ada L. Observation of arm behaviour in healthy elderly people: implications for contracture prevention after stroke. *Aust J Physiother*. 2006;52:129–33.

40 Vermeulen HM, Stokdijk M, Eilers PH, et al. Measurement of three-dimensional shoulder movement patterns with an electromagnetic tracking device in patients with a frozen shoulder. *Ann Rheum Dis*. 2002;61:115–120.

41 Fayad F, Roby-Brami A, Yazbeck C, et al. Three-dimensional scapular kinematics and scapulohumeral rhythm in patients with glenohumeral osteoarthritis or frozen shoulder. *J Biomech*. 2008;41:326–332.

42 Ogston JB, Ludewig PM. Differences in 3-dimensional shoulder kinematics between persons with multidirectional instability and asymptomatic controls. *Am J Sports Med*. 2007;35:1361–1370.

43 Hébert LJ, Moffet H, McFadyen BJ, Dionne CE. Scapular behavior in shoulder impingement syndrome. *Arq Bras Med Re- habil*. 2002;83:60–69.

44 Lee TS, Kilbreath SL, Refshauge KM, et al. Pectoral stretching program for women undergoing radiotherapy for breast cancer. *Breast Cancer Res Treat*. 2007;102:313–321.

45 Lee TS, Kilbreath SL, Refshauge KM, et al. Prognosis of the upper limb following surgery and radiation for breast cancer. *Breast Cancer Res Treat*. 2008;110:19–37.

46 Box RC, Reul-Hirche HM, Bullock-Saxton JE, Furnival CM. Shoulder movement after breast cancer surgery: results of a randomized controlled study of postoperative physiotherapy. *Breast Cancer Res Treat*. 2002;75:35–50.