DIFFERENCES IN UPPER BODY POSTURE AND POSTURAL MUSCLE ACTIVATION IN FEMALES WITH LARGER BREAST SIZES

by

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The following individuals read and discussed the thesis submitted by student Mindy Elizabeth Bennett, and they also evaluated her presentation and response to questions during the final oral examination. They found that the student passed the final oral examination, and that the thesis was satisfactory for a master's degree and ready for any final modifications that they explicitly required.

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ABSTRACT

Differences in Upper Body Posture and Postural Muscle Activation in Females with Larger Breast Sizes

Breast hypertrophy is a common medical condition whose morbidity has increased over recent decades. Symptoms of breast hypertrophy often include musculoskeletal pain in the neck, back and shoulders, and numerous psychosocial health burdens. To date, reduction mammaplasty (RM) is the only treatment shown to significantly reduce the severity of the symptoms associated with breast hypertrophy. However, due to a lack of scientific evidence in the medical literature justifying the medical necessity of RM, insurance companies often deny requests for coverage of this procedure. Therefore, the purpose of this study is to investigate biomechanical differences in the upper body of women with larger breast sizes in order to provide scientific evidence of the musculoskeletal burdens of breast hypertrophy to the medical community

Twenty-two female subjects (average age 25.90, ± 5.47 years) who had never undergone or been approved for breast augmentation surgery, were recruited to participate in this study. Kinematic data of the head, thorax, pelvis and scapula was collected during static trials and during each of four different tasks of daily living. Surface electromyography (sEMG) data from the Midcervical (C-4) Paraspinal, Upper Trapezius, Lower Trapezius, Serratus Anterior, and Erector Spinae muscles were recorded in the same activities. Maximum voluntary contractions (MVC) were used to normalize the sEMG data, and %MVC during each task in the protocol was analyzed. Kinematic data from the tasks of daily living were normalized to average static posture data for each subject. Subjects were divided into groups of normal control subjects (n=12, reported bra-cup size A, B, or C) or hypertrophy subjects (n=10, reported bra-cup size D or larger). To compare results between the groups, a two-tailed independent t-test was performed for each dependent variable with significance set at $\alpha=0.05$.

Significant differences in torso flexion were found between the normal control group and the hypertrophy group during both the pencil activity (p=0.054) and the step up activity (p=0.001). There were also significant differences in lower trapezius muscle activation during the static trial (p=0.051). Although not significant, women in the hypertrophy group also tended to exhibit greater head flexion, pelvic tilt and torso flexion under static conditions, and also exhibited increased muscle activation in all five muscles under the same conditions.

Results of this study provide scientific information regarding the effects of breast hypertrophy on the musculoskeletal system. While none of the postural alterations seen in women with large breasts were significantly different from those seen in women with smaller breasts, the data presented shows a trend towards altered musculoskeletal alignment due to the size and weight of larger breasts that should be considered when determining the medical necessity of reduction mammaplasty.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Breast hypertrophy is a common medical condition whose morbidity has increased over recent decades. While the exact definition of breast hypertrophy is unclear, it is characterized by an increase in the volume and weight of breast tissue beyond normal proportions [1]. The exact etiology of breast hypertrophy is unknown, especially when it occurs during puberty and early adolescence.

Common symptoms associated with breast hypertrophy include pain in the neck, back and shoulders, intertrigo, shoulder grooving from bra straps, headaches, rash, and breast pain [2-9]. Women with breast hypertrophy may also report neurologic symptoms of the upper extremity such as ulnar nerve neuropathies, hand numbness, and carpal tunnel syndrome [1, 4, 8-14].

Psychosocial burdens are also associated with breast hypertrophy. Many women with breast hypertrophy report feelings of embarrassment, difficulty finding properly fitting clothing, low self-esteem, and difficulty participating in sports [12, 13, 15, 16]. As a result, women with hypertrophic breasts are often dissatisfied with their self-image and may seek reduction mammaplasty as a way to reduce both pain and psychosocial distress.

To date, there is no lasting non-operative treatment for breast hypertrophy [1]. As a result, women with severe breast hypertrophy are most often treated by reduction mammaplasty. Bilateral reduction mammaplasty is a surgical technique in which excess breast tissue is removed from both breasts. Objectives of reduction mammaplasty include: lifting of the nipple and areola, reduction of the breast skin envelope, overall improvement in the shape of the breast, and preservation of lactation and breast sensitivity [17, 18]. Reduction mammaplasty is the only treatment proven to effectively reduce the severity of the symptoms associated with breast hypertrophy.

Over the past few years reduction mammaplasty has become one of the most common reconstructive surgical procedures performed by plastic surgeons in the United States. The number of reduction mammaplasty surgeries performed each year has increased 25% since 2000. In 2007, 106,179 breast reductions were performed, making reduction mammaplasty the number five reconstructive procedure in 2007 [19].

Recent research has examined the correlation between the relief of the symptoms of breast hypertrophy and surgery. Most recently, a study entitled “Breast Reduction: Assessment of Value and Outcomes” (BRAVO) was performed using validated self-report questionnaires to evaluate the burden of breast hypertrophy. This multicenter study comparatively assessed both women presenting for breast reduction and a control group of large-breasted women. This study found that women presenting for surgery experienced more breast-related symptoms (especially pain) relative to the control group, were unable to obtain long-term relief of symptoms form conservative treatments, and reported substantial pain relief following breast reduction surgery, essentially allowing them to return to normal functioning. Based on the results of this study, Kerrigan et al were able to define the medical necessity of breast reduction surgery, and determined that women reporting two or more of the key physical symptoms all or most of the time had the most substantial health burden and were most likely to benefit from surgery [1, 20].

Despite increasing recognition of breast hypertrophy as a morbid disease, the debate over whether reduction mammaplasty should be considered a cosmetic or reconstructive procedure continues. While many prospective studies have been published indicating the positive health related outcomes of reduction mammaplasty, no studies to date have provided solid objective measurements as evidence of variables that indicate when reduction mammaplasty becomes medically necessary. As a result, insurance companies often reject patients who do not meet their arbitrary requirements for determining medical necessity despite having obvious symptoms.

Problem Statement

The purpose of this study is to investigate biomechanical differences in the upper body of women with larger breast sizes in order to provide scientific evidence of the musculoskeletal burdens of breast hypertrophy to the medical community. For the purposes of this study, subjects were divided into groups of normal control subjects (reported bra-cup size A, B, or C) or hypertrophy subjects (reported bra-cup size D or larger) [21]. The evaluation of each subject has three primary objectives:

Objective 1

Quantify the kinematics of the head, thorax, pelvis and scapula during different tasks of daily living in comparison to the same kinematics during a static standing trial. The kinematic variables of interest will be: Head flexion and extension, thoracic flexion and extension, pelvic tilt, scapular protraction and retraction, scapular upward rotation, and lateral torso flexion.

Objective 2

Quantify the maximum amplitude (%MVC) of muscle activation of each of the muscles of interest during each task of daily living in comparison to the maximum amplitude (%MVC) of muscle activation of each muscle during a static standing trial.

Objective 3

Quantify the health burden of breast hypertrophy based on the breast symptom summary score (BSS), calculated from the Breast Related Symptoms Questionnaire (BRSQ).

Research Hypothesis

Based on these three objectives, the research hypothesis for this study is that the BSS scores, upper body biomechanics, and cervico-thoracic muscle activation will differ between the two groups due to the size and weight of their breasts. Based on the research hypothesis for this study, the statistical hypotheses in terms of the null hypothesis (H_o) and alternative hypothesis (H_a) for this study are:

- $H_o = \mu_1 = \mu_2$ (Normal control subjects and Hypertrophy subjects will exhibit the same)
    - BSS scores
    - Muscle Activation
    - Head Flexion and Extension
    - Torso Flexion and Extension

  - Pelvic Tilt
  - Scapular Protraction and Retraction
  - Scapular Rotation
  - Lateral Torso Flexion
- $H_a = \mu_1 \neq \mu_2$ (Normal control subjects and Hypertrophy subjects will exhibit different)
  - BSS scores
  - Muscle Activation
  - Head Flexion and Extension
  - Torso Flexion and Extension
  - Pelvic Tilt
  - Scapular Protraction and Retraction
  - Scapular Rotation
  - Lateral Torso Flexion

Assumptions

- It is assumed that subjects performed each task as they would if no one was watching them so that movement can be accurately assessed and normalized across tasks.
- All subjects were required to wear a regular (non sports) bra during testing. It is assumed that the support given by the bra (i.e. location of bra straps, presence of

underwire) is uniform across all subjects and has minimal, if any, effect on the biomechanics of the musculoskeletal system.

Limitations

The results of this study will be limited by the group of women represented in the sample population: women over the age of 18 who have never undergone or been approved for breast augmentation surgery.

Delimitations

This study will be applicable to all females who have never undergone breast augmentation surgery.

Operational Definitions

This study will examine 8 distinct dependent variables, each of which presents a specific method of measurement.

- *Breast Related Symptoms Scores (BSS):* Computed by averaging the item scores from the Breast Related Symptoms Questionnaire and linearly transforming the average to a 0-to-100 scale.
- *Muscle Activation*: Reported as a percentage of maximum muscle contraction for each muscle of interest

- *Head Flexion*: Quantified using a 6-camera optical motion camera system and reported in units of degrees. Values were normalized as an average of the maximum change from static measurements, with positive values representing head flexion.
- *Torso Flexion and Extension*: Quantified using a 6-camera optical motion camera system and reported in units of degrees. Values were normalized as an average of the maximum change from static measurements, with positive values representing torso flexion.
- *Pelvic Tilt*: Quantified using a 6-camera optical motion camera system and reported in units of degrees. Values were normalized as an average of the maximum change from static measurements, with positive values representing anterior tilt.
- *Scapular Protraction*: Quantified using a 6-camera optical motion camera system and reported in units of degrees. Values were normalized as an average of the maximum change from static measurements, with positive values representing shoulder protraction.
- *Scapular Upward Rotation*: Quantified using a 6-camera optical motion camera system and reported in units of degrees. Values were normalized as an average of the maximum change from static measurements, with positive values representing upward rotation.

- *Lateral Torso Flexion*: Quantified using a 6-camera optical motion camera system and reported in units of degrees. Values were normalized as an average of the maximum change from static measurements, with positive values representing flexion towards the left side of the body.

BSS scores will only be computed at the beginning of the data collection since that is the only time they will be measured. The remaining dependent variables will be measured during both static trials and during each task of daily living trial with the exception of scapular upward rotation and lateral torso flexion, which will only be measured during lift and static trials.

REVIEW OF LITERATURE

Breast hypertrophy has been widely associated with both physical and psychosocial symptoms. Many qualitative studies have provided insight on the lessening of severity of these symptoms following reduction mammaplasty, yet few studies have aimed to explain the mechanism of the musculoskeletal pain seen among women with larger breasts.

While several surgical procedures have been presented to achieve reduction in breast size, the degree of relief of breast hypertrophy symptoms does not appear to be related to the surgical procedure chosen. Therefore, for the purposes of this study, the different types of surgical procedures will not be outlined and this review will focus solely on breast hypertrophy and its effects on the spinal column, the health-related quality of life of women with breast hypertrophy, alternative methods of treatment, and determination of coverage by third party payers.

Breast Hypertrophy and the Spinal Column

Deviated posture of the head, neck and shoulders has long been recognized as a potential contributing factor of the onset of upper body musculoskeletal pain. Posture is maintained by ligamentous and muscular support as a result of the body’s effort to remain erect [8]. Research suggests that breast hypertrophy causes postural alterations related to the skeletal system, specifically the spinal column.

In general, the spinal column is a fairly flexible unit which can change shape on a limited basis in order to adjust to the location of the body’s center of gravity [8]. In individuals without significant postural deviations, the center of gravity of the human body profile passes from the external auditory meatus, through the odontoid process, slightly posterior to the center of the hip joint, slightly anterior to the center of the knee, and to a point slightly anterior to the lateral malleoli [8, 22]. However, in women with breast hypertrophy, the nipple descends to a lower position than the ideal [1], leading to secondary effects related to the location of the center of gravity. This change in location of the center of gravity causes increased curvature of the cervical spine (increased cervical lordosis or head flexion) and increases the tension in the cervical extensor muscles [5, 8].

The increased curvature of the cervical spine commonly seen in women with hypertrophic breasts may also place the head and shoulders forward, causing further postural alterations. Forward head position is defined as excessively anterior position of the head in relation to a theoretical plumb line perpendicular to the body’s center of gravity [23]. It has been postulated that forward head position of the head may result in a sustained isometric contracture of the neck muscles [8, 24]. As mentioned before, pain in the head, neck and shoulders are common symptoms seen in women with breast hypertrophy [2-9]. These common symptoms may be explained as a result of the fatigue experienced by the muscles in the neck while trying to maintain this faulty forward head position [8, 23].

Forward head position has also been associated with an increase in thoracic kyphosis angle and may also lead to a downward rotation of the scapula and acromion, placing the shoulders in a deviated forward position [8, 24, 25]. This altered scapula position may decrease the range of motion of the upper extremity and change the biomechanics of the shoulder joint, resulting in musculoskeletal pain over time.

In women with breast hypertrophy, the altered position of the scapula due to the weight of the breasts may lead to swelling and stiffness of the rotator cuff and can induce painful, limited motion of the shoulder girdle [8, 24]. Thus, women who suffer from breast hypertrophy may suffer from functional disabilities in the upper body, and may be limited in their ability to perform tasks of daily living due to decreased range of motion of the shoulder girdle.

Changes in skeletal alignment may promote muscular changes that create excessive or abnormal muscle tension. Posturally induced muscle weakness has been defined as the effect on muscles of remaining in a lengthened condition, however slight, beyond the neutral (physiological rest) position [26]. Therefore, if a muscle becomes positionally elongated, it is likely that this muscle will become relatively weak over time. Similarly, a muscle that becomes positionally shortened will become relatively stronger over time.

Changes in the direction of muscle pull as a result of an altered scapula position may affect the amount of muscle tension required to maintain a static position [23], thus inducing fatigue and weakness in the scapula musculature similar to that seen in patients who present with shoulder impingement syndrome. Kisner and Colby suggest that increased scapular abduction or a “forward shoulders” posture may be partly caused by weakness of the scapular retractors, such as the upper trapezius, lower trapezius, and rhomboid muscles [26]. Similarly, Zimmerman et al propose that heavy breasts lead to gradual and continuous tension on the middle and lower trapezius muscle fibers consequently contributing to the shoulder pain in women with breast hypertrophy present [8].

Along with musculoskeletal pain, women with breast hypertrophy may present with neurological complications. It has also been suggested by several authors that the altered position of the scapula results in compression of the brachial plexus, thus leading to neurologic complications of the upper extremity [10, 27]. Neurologic complications often include ulnar nerve paresthesis, hand numbness and carpal tunnel syndrome [4, 8-14]. It is speculated that the brachial plexus compression between the coracoid process of the scapula and the rib cage occurs as forward depression of the shoulders tilts the coracoid downward in women with breast hypertrophy [10].

In a study by Kaye et al, it was found that almost all women tested presented with characteristic area of ulnar hypesthesia in each hand regardless of complaints of pain or numbness in their hands [27]. While ulnar hypesthesia should not be disregarded as a symptom seen in women with breast hypertrophy, it is important to note that this study gives very little information about the methods used to gather data, and should therefore not be treated as true scientific evidence of its association with the symptoms of breast hypertrophy.

Health-Related Quality of Life

Breast hypertrophy has been shown to create significant social and psychological problems for the women who suffer from this condition. Major psychosocial complaints of women presenting with breast hypertrophy include: unwanted attention, poor self-esteem, difficulty finding proper fitting clothing, difficulty and embarrassment during exercise, negative impact on intimate relationships, and avoidance of social occasions [2, 4, 15, 28].

A myriad of physician-based questionnaires have been used in an attempt to evaluate the health-related quality of life of women with hypertrophic breasts. One of the most well documented tools for evaluating physical and mental health-related quality of life is Short Form 36 [2, 14, 21, 28, 29]. Short Form 36 (SF-36) includes eight domains: physical function and activities, daily activities, emotional status, social activities, mental health, vitality and energy, pain, and general health perceptions. For each domain, higher scores indicate better health status and higher quality of life [21].

Several studies on outcomes of reduction mammaplasty have shown that women with symptoms of breast hypertrophy score significantly lower preoperatively on SF-36 than women representing the normal population [2, 7, 13, 14, 17, 21, 28-30]. These findings indicate that women who suffer from breast hypertrophy have a lower perceived health-related quality of life than the normal female population. These same studies also found that despite low preoperative scores on SF-36, reduction mammaplasty resulted in improved postoperative (3 to 12 months) scores on SF-36 [2, 14, 21, 28, 30]. Most notably, a prospective questionnaire study conducted by Blomqvist et al in 2000 evaluated reduction mammaplasty patients SF-36 scores preoperatively and postoperatively (6 and 12 months) in comparison to an age-matched group of Swedish women. In this study, patients who underwent reduction mammaplasty scored significantly higher on SF-36 6 and 12 months postoperatively and were similar to the SF-36 scores for the age-matched group [2]. These results not only indicate improvement, but normalization.

More recently, Kerrigan et al developed a new self-report questionnaire in order to systematically quantify breast-specific symptoms. The Breast Related Symptoms Questionnaire (BRSQ) is a 13-item condition specific questionnaire which encompasses both psychological and physical symptoms typically seen in women with breast hypertrophy. In their study associated with the BRAVO (Breast Reduction: Assessment of Value and Outcomes) study, Kerrigan et al found that women who presented for surgical correction of their breast hypertrophy scored more poorly on the BRSQ than did both the hypertrophy control subjects (bra cup size ≥ D) and the normal control subjects (bra cup size A, B, or C) [21]. Results from this extensive study suggest that symptoms are a better indicator of which women have the greatest health burden than are physical measurements such as breast volume.

The data from all these studies clearly demonstrates that breast hypertrophy has a significant impact on a women's health-related quality of life and that symptoms of breast hypertrophy are a legitimate indicator of medical necessity for reduction mammaplasty surgery. More importantly, there is no evidence provided in these studies that indicates that patient satisfaction or symptom improvement is enhanced with a greater amount of tissue removed [12], further supporting the fact that reduction should be considered a medically necessary procedure and not cosmetic in nature.

Alternatives to Reduction Mammaplasty

Insurance companies often require women who present with breast hypertrophy to try other forms of nonsurgical pain treatment before they will cover the costs of surgery. The length of time insurance companies require the patient to participate in nonsurgical therapy for management of pain ranges from six weeks to six consecutive months [11, 31-34]. Common nonsurgical pain treatments include weight loss, aerobic exercise, use of specialized support bras, stretching, strength exercises and postural training, relaxation, heat application, hydrotherapy, back brace, medications, chiropractic treatment, acupuncture and physical therapy. [1, 28].

While some nonsurgical treatments may provide temporary relief of pain, none of these treatments have been shown to provide full operative relief to woman seeking reduction mammaplasty surgery [28]. One of the most common nonsurgical treatments many insurance companies require patients to try is weight loss due to their requirements that patients be within 20% of ideal body weight prior to surgery [32]. This criterion is set under the premise that a lower body weight or body mass index will result in a greater relief of symptoms. However, research evidence does not support this assumption as it has been shown that symptom relief is independent of preoperative weight [14]. While weight reduction alone may have an effect on the breast, it will not change body proportion or breast position, and cannot therefore be expected to relieve symptoms of breast hypertrophy [1]. The American Society of Plastic Surgeons states that despite the fact that weight reduction may be beneficial to the patient’s overall health, it is not a pre-requisite for reduction mammaplasty surgery [1], a statement clearly being overlooked by insurance companies.

Other forms of nonsurgical treatments have also been shown to not provide full relief of breast hypertrophy symptoms, and in some cases do not provide any relief. Orthotic brassieres have been shown to provide some relief, but often substitute increased discomfort in the shoulders through pressure created by the straps [1]. In the BRAVO study conducted by Kerrigan et al, patients presenting for surgery were asked to report any prior nonsurgical attempts to relieve their breast-related symptoms. The four most common alternative treatments reported were weight loss, supportive bras, medications and physical therapy [28]. Of the women surveyed, less than 1% found full permanent relief with medications and heat applications and none reported full permanent relief with other nonsurgical treatments [1, 28]. Also, over half of those women who had tried several treatments, including weight loss, support bras, strengthening exercises and postural training, reported no relief from these treatments [1, 28].

Medical Coverage by Third Party Payers

Despite increasing recognition of breast hypertrophy as a morbid condition, there is still great debate between plastic surgeons and insurance companies over when reduction mammaplasty is considered medically necessary and therefore eligible for insurance coverage. One foreseeable issue with determining medical necessity is that the guidelines by which insurers determine eligibility for coverage of reduction mammaplasty rely largely on subjective materials [35]. As a result, the criterion insurance companies choose to use to determine coverage is often inconsistent resulting in decisions for coverage that are not always equitable.

One criterion that is uniform across medical policies and consistent with the definition of cosmetic surgery provided by the American Society of Plastic Surgeons is that reduction mammaplasty will not be considered medically necessary when it is performed solely for the purpose of treating psychological and psychosocial complaints related to appearance [11, 31-33]. The American Society of Plastic Surgeons (ASPS) states that justification for reduction mammaplasty should be based on the probability of relieving the clinical signs and symptoms of macromastia. The ASPS also recommends that coverage be based on documented symptoms of macromastia regardless of body weight or weight of breast tissue removed [36].

Regardless of the ASPS recommendations and documentation by the American Medical Association clearly defining the distinction between cosmetic and reconstructive procedures, many insurance companies apply various criteria of their own in determining medical necessity. Most commonly, insurance companies establish a minimal amount of breast tissue that must be removed in order to establish eligibility [1]. In a study done by Krieger et al it was reported that sixty-nine percent of responding managed-care organizations used weight of excised tissue as the primary criterion for coverage [37].

A meta-analysis of published studies found that a cut-off value of 350 grams is one of the most common requirements for medical necessity by third-party payers [3]. However, Kerrigan et al reported that most insurance carriers use a 500g/breast tissue as a cutoff irrespective of body habitus or patients' presenting symptoms [20]. These differences in reported criteria for minimum amount of breast tissue to be removed support arguments by health care providers that using the weight of excised breast tissue as a primary criterion for establishing medical necessity is arbitrarily based on retrospective studies rather than scientific evidence.

Many insurance companies use the Schnur Sliding Scale as a standard tool to determine medical necessity [3, 31, 32, 34, 38]. The Schnur sliding scale was developed by Schnur et al in 1991 as an attempt to create a decision rule about the medical necessity for reduction mammaplasty. The scale proposes a "sliding" adjustment of required resection weight of breast tissue to be removed based on a woman's body surface area [20].

The logic behind the Schnur sliding scale comes from physician's opinions on their patient's motivation for surgery. The scale proposes that when the amount of breast tissue to be removed compared to the woman's body surface area lies above the 22nd percentile line the patient’s motivations are mostly functional and it should be considered medically necessary for the patient to undergo reduction mammaplasty surgery. However, when the amount of tissue to be removed falls below the fifth percentile line, the model’s authors suggest that these women are seeking surgery for purely cosmetic reasons. The authors also propose that women who fall in between the two lines have a mixture of cosmetic and functional needs for the surgery and are considered on a case to case basis [20, 35].

Despite the wide use of the Schnur sliding scale by insurance companies as a criterion to determine the medical necessity of reduction mammaplasty, the legitimacy of the scale has been questioned. Seitchik questioned Schnur’s work stating that it cannot be assumed that patients registered below the fifth percentile were the same ones who undertook surgery for only cosmetic reasons [35]. Based on a retrospective study of his own patients, Seitchik concluded that a graded, three-level minimum specimen weight standard would be more equitable for determining medical necessity [35]. However the criteria developed in his study are much less restrictive than the 500g/breast minimum rule used as a cutoff by many insurance carriers.

As part of the BRAVO study conducted by Kerrigan et al, researchers investigated the scientific basis of both the Schnur sliding scale and the 500g/breast minimum rule established by insurance companies. Findings from this study showed that in women undergoing reduction mammaplasty, neither the Schnur siding scale nor the 500-g minimum rule was able to successfully predict which group of women would gain greater improvement from surgery as measured by 5 validated measures of health burden [20]. As a result, Kerrigan et al concluded that the benefits of reduction mammaplasty are not significantly associated with weight of resection, and recommended that breast hypertrophy be defined by a breast volume in the top 10th percentile (>750cc) of the U.S. population or a minimum bra cup size D[20, 28].

Spector et al published a study in 2007 supporting findings from the BRAVO study that symptom improvement and patient satisfaction is independent of the amount of breast tissue removed. In this study, patients were given a custom-designed questionnaire designed to evaluate breast-hypertrophy related symptoms and quality of life factors preoperatively and then given the same questionnaire at their final postoperative visit three to twelve months after surgery. Results of this study showed that all 59 women who had resection weights of less than 1000g showed significant decreases in breast hypertrophy related symptoms analyzed including upper back pain, lower back pain, neck pain, breast pain, headaches and shoulder pain. These same women also showed significant improvements in all quality of life factors analyzed including difficulty buying clothes and bras, difficulty participating in sports, and difficulty running [39]. Spector et al also did a second study on 188 patients in 2008 and found that prior to surgery, women have the same symptom burden across all breast sizes and that the symptomatic improvement derived from reduction mammaplasty is not significantly different between women with different breast sizes [40].

Summary

In summary, the task of defining medical necessity in the case of reduction mammaplasty is complex. Most women who suffer from breast hypertrophy present with similar physical and psychosocial symptoms and may also present with functional disabilities due to improper positioning of the head and scapula. While there are many nonsurgical treatment options available to help reduce symptoms of breast hypertrophy reduction mammaplasty is the only treatment option shown to significantly improve symptoms of breast hypertrophy. However, there is a lack of objective measurements providing evidence of the medical necessity of reduction mammaplasty to relieve symptoms of breast hypertrophy. As a result, insurance companies are forced to make medical coverage decisions based on subjective evidence found in the medical literature.

In an attempt to provide scientific evidence of the medical necessity of reduction mammaplasty to relieve symptoms of breast hypertrophy, the current study will investigate the musculoskeletal burdens of breast hypertrophy in women who do not present for reduction mammaplasty surgery. It is theorized that women with larger breasts will exhibit both structural alterations and increased muscle activation due to the size and position of their breasts in comparison to women with smaller breast sizes.

METHODS

This chapter addresses the methodology and procedures used to accomplish the objectives of this study. Topics to be outlined in this chapter will include: mathematical definitions for all kinematic variables, equations for establishing local coordinate systems for each body segment of interest, equations and definitions of muscle activation, description of the health-measure instrument used, the experimental protocol, and the statistical methods used to evaluate the significance of the resulting data from this study.

Kinematics

Previous research has shown that breast hypertrophy causes postural alterations due to a change in the location of center of gravity [5,8]. Therefore, to fully understand the burdens of breast hypertrophy on the skeletal system, it was necessary to quantify the movements of the segments of the upper body during tasks of daily living. Kinematic data of the upper body was tracked using a 6-camera optical motion camera system (Vicon, 250 HZ). This system works by tracking the position of reflective spherical surface markers mounted on the skin surface. For static calibration of the system, surface markers were placed on anatomical landmarks of the head, scapula, thorax, and pelvis (described below in anatomical surface marker section). In addition, a solid triad of markers was placed on the scapula segment. Simultaneous acquisition of coordinate systems for both the anatomically based landmarks of the scapula and the triad allowed for removal of the anatomical markers of the scapula during trials, and improved accuracy of the results.

Kinematic Model

Kinematics of the upper body were quantified using a four-segment model comprised of the head, scapula, thorax and pelvis. Kinematic data was obtained in order to quantify movement in the head, thorax, pelvis, and scapula during each task of daily living. Once this data is known, it can be compared to the same kinematic data for the static trials in order to get an idea of the biomechanics of the upper body used to perform each task of daily living.

Anatomically Based Landmarks

Local coordinate systems for each segment were established by placing surface markers over at least three anatomically based landmarks in each segment. The locations of the markers for the head, thorax, pelvis and scapula are as follows:

- Head (Figure 1.)
    - Left front head (LFHD): Point of the left anterior side of the head
    - Right front head (RFHD): Point of the right anterior side of the head
    - Left back head (LBHD): Point of the left posterior side of the head
    - Right back head (RBHD): Point of the right posterior side of the head

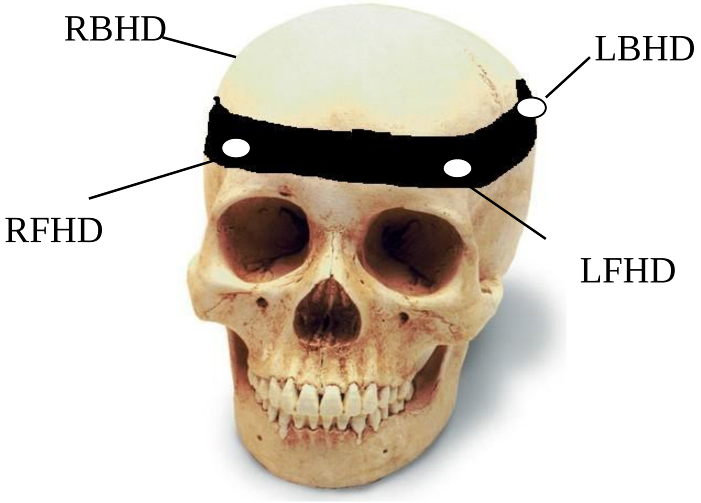

Figure 1. Location of Head Markers

- Thorax (Figure 2.)
    - Seventh Cervical Vertebrae (C7): Spinous process of the seventh cervical vertebrae
    - Sixth Thoracic Vertebrae (T6): Spinous process of the sixth thoracic vertebrae
    - Twelfth Thoracic Vertebrae (T12): Spinous process of the twelfth thoracic vertebrae

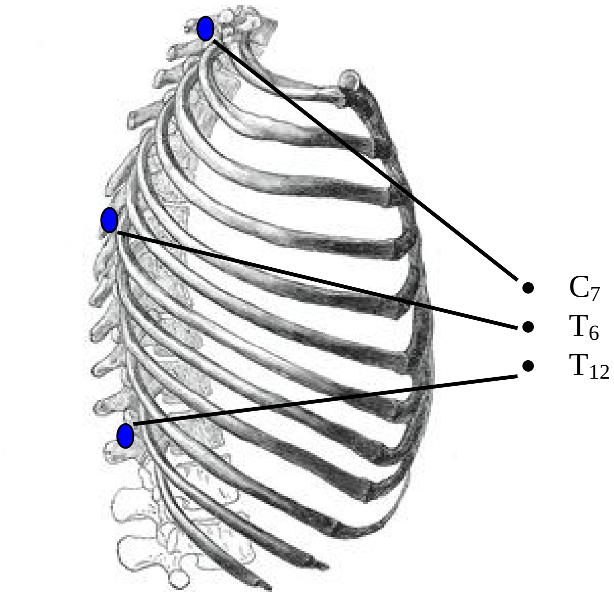

Figure 2. Location of Thorax Markers

- Pelvis (Figure3.)
  - Left Anterior Superior Iliac Spine (LASI): Anterior extremity of the iliac crest of the pelvis on the left side
  - Right Anterior Superior Iliac Spine (RASI): Anterior extremity of the iliac crest of the pelvis on the right side
  - Left Posterior Superior Iliac Spine (LPSI): Posterior extremity of the iliac crest of the pelvis on the left side
  - Right Posterior Superior Iliac Spine (RPSI): Posterior extremity of the iliac crest of the pelvis on the right side

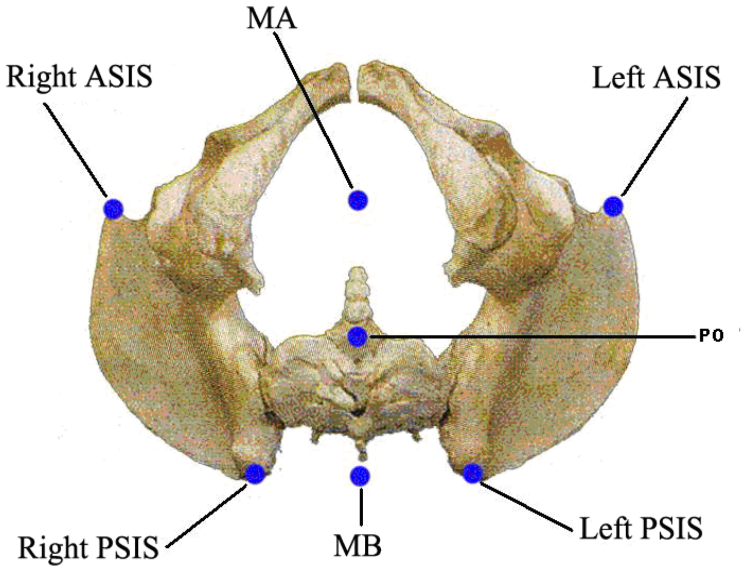

Figure 3. Location of Pelvic Markers (Inferior View)

- Scapula (Figure 4.)
    - Trigonum Spine (TS): Midpoint of the triangular surface on the middle border of the scapula, in line with the scapular spine
    - Angulus Acromialis (AA): The most laterodorsal point of the scapula
    - Inferior Angle (AI): The most caudal point of the scapula

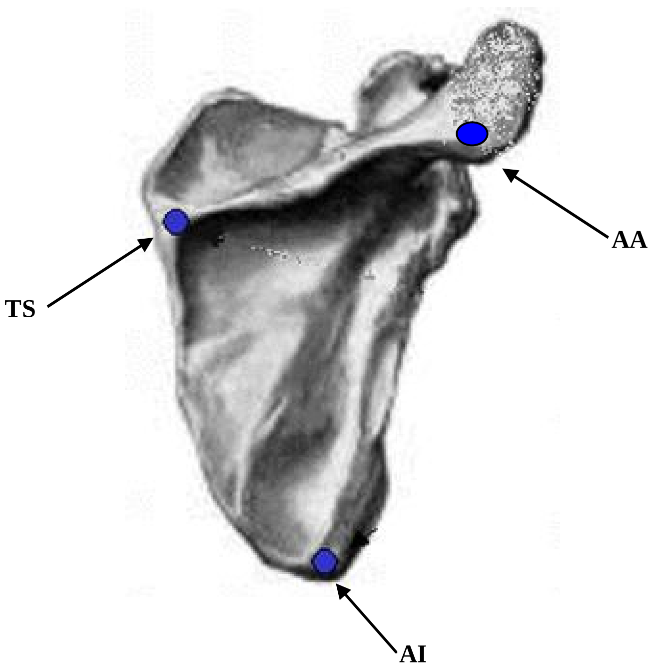

Figure 4. Location of Scapula Markers (Posterior View)

Local Coordinate Systems

With at least three known anatomically based coordinates, a local coordinate system can be established for each body segment of interest. The methods used to create local coordinate systems for the head, thorax, pelvis and scapula is described below.

- Head (Figure 5): The origin of the head coordinate system (H_0) was located at the center of the head. The location of H_0 was calculated by calculating the midpoint of the line connecting the midpoint of the two anterior markers (LFHD and RFHD) and the two posterior markers (LBHD and RBHD) using the following equations:

- Midpoint (H_F) of the two anterior markers (LFHD and RFHD)

$$H_F = (LFHD+RFHD)/2$$

Equation 1.

- Midpoint (H_B) of the two posterior markers (LBHD and RBHD)

$$H_B = (LBHD+RBHD)/2$$

Equation 2.

- Location of the origin (H_0)

$$H_0 = (H_F + H_B)/2$$

Equation 3.

The x-axis (H_X) of the head coordinate system was a unit vector pointing in the anterior direction from H_0 to H_F.

$$H_X = \frac{(H_F - H_0)}{\|H_F - H_0\|}$$

Equation 4.

The z-axis (H_Z) of the head coordinate system was a unit vector pointing in the superior direction and was the cross product of H_X and a unit vector pointing from H_0 to LFHD.

$$H_Z = \frac{H_X \times (LFHD - H_0)}{\|H_X \times (LFHD - H_0)\|}$$

Equation 5.

Finally, the y-axis (H_Y) of the head coordinate system was a unit vector pointing to the left, and was the cross product of H_Z and H_X.

$$H_Y = \frac{H_Z \times H_X}{\left\| H_Z \times H_X \right\|}$$

Equation 6.

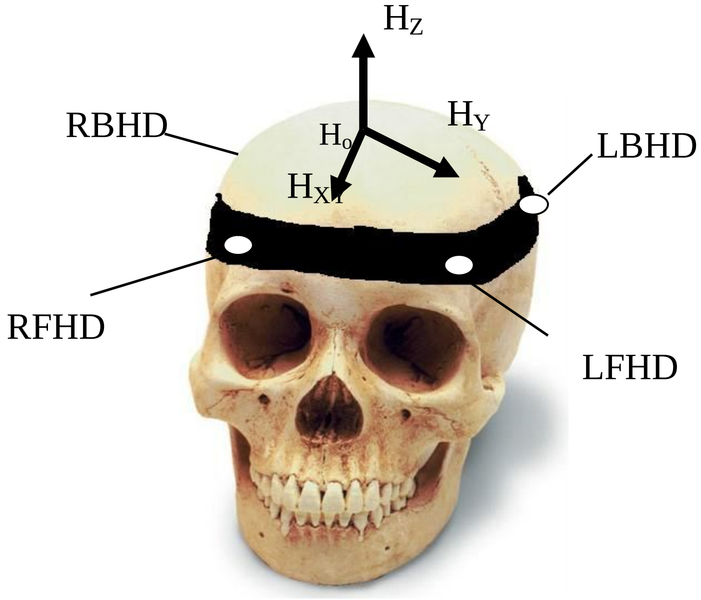

Figure 5. Head Coordinate System

- Thorax (Figure 6.): The origin of the thorax coordinate system (T_0) was located at the twelfth thoracic vertebrae (T_{12}). The z-axis (T_Z) of the thorax coordinate system was a unit vector pointing in the superior direction from T_0 to the seventh cervical vertebrae (C_7).

$$T_Z = \frac{(C_7 - T_0)}{\|C_7 - T_0\|}$$

Equation 7.

The y-axis (T_Y) of the thorax coordinate system was a unit vector pointing to the left and was the cross product of a unit vector pointing from C_7 to T_6 and T_Z.

$$T_Y = \frac{(T_6 - C_7) \times T_Z}{\|(T_6 - C_7) \times T_Z\|}$$

Equation 8.

Finally, the x-axis of the thorax coordinate system was a unit vector pointing in the anterior direction and was the cross product of T_Y and T_Z.

$$T_X = \frac{T_Y \times T_Z}{\|T_Y \times T_Z\|}$$

Equation 9.

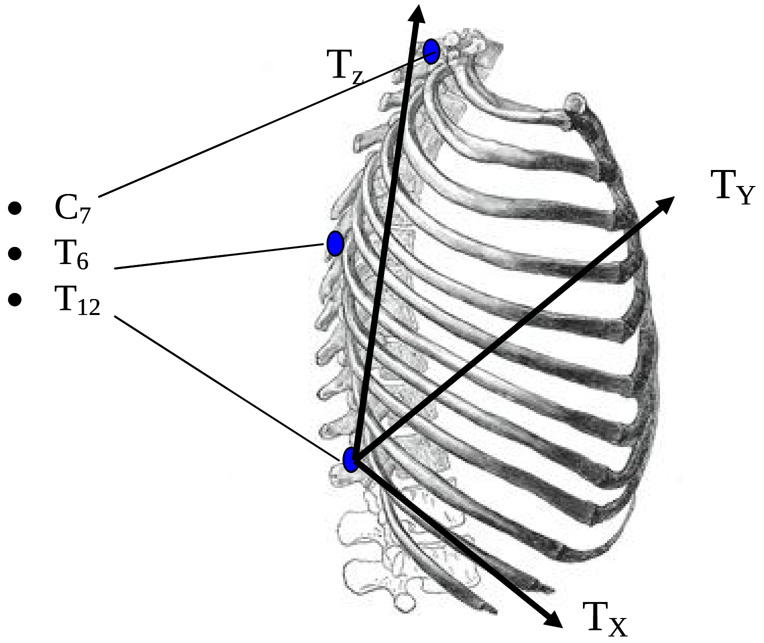

Figure 6. Thorax Coordinate System

- Pelvis (Figure 7.): The origin of the pelvic coordinate system (P_0) was located at the center of the pelvis. The location of P_0 was calculated by calculating the midpoint of the line connecting the midpoint of the two anterior markers (LASI and RASI) and the two posterior markers (LPSI and RPSI) using the following equations:
  - Midpoint (M_A) of the two anterior markers (LASI and RASI)

$$M_A = (LASI+RASI)/2$$

Equation 10.

  - Midpoint (M_P) of the two posterior markers (LPSI and RPSI)

$$M_P = (LPSI+RPSI)/2$$

Equation 11.

- Location of the origin (P_0)

$$P_0 = (M_A + M_P)/2$$

Equation 12.

The x-axis (P_X) of the pelvis coordinate system was a unit vector pointing in the anterior direction from P_0 to M_A.

$$P_X = \frac{(M_A - P_0)}{\|M_A - P_0\|}$$

Equation 13.

The z-axis (P_Z) of the pelvis coordinate system was a unit vector pointing in the superior direction and was the cross product of P_X and a unit vector point from P_0 to LASI.

$$P_Z = \frac{P_X \times (LASI - P_0)}{\|P_X \times (LASI - P_0)\|}$$

Equation 14.

Finally, the y-axis (P_Y) of the pelvis coordinate system was a unit vector pointing to the left, and was the cross product of P_Z and P_X.

$$P_Y = \frac{P_Z \times P_X}{\|P_Z \times P_X\|}$$

Equation 15.

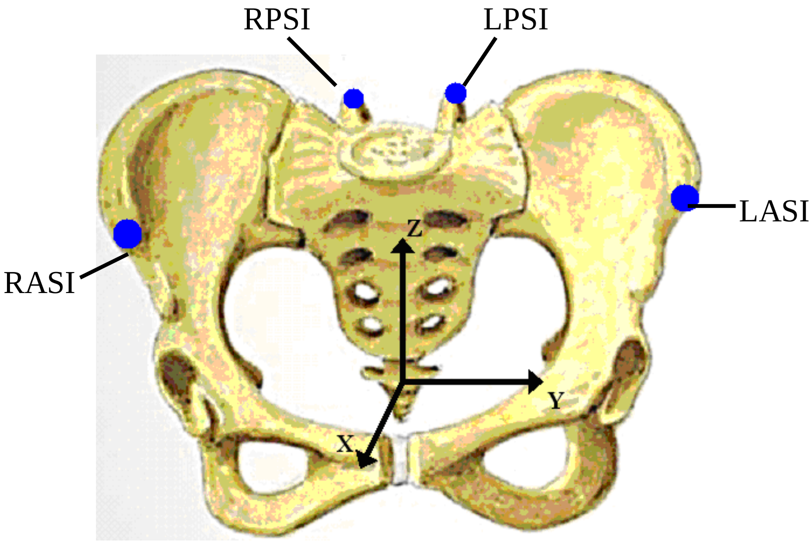

Figure 7. Pelvic Coordinate System

- Scapula (Figure 10.): As described earlier, a triad was placed on the scapula segment during data collection in order to better facilitate data collection of the scapular region. Use of the triad required the establishment of a triad coordinate system. A rotation matrix was used to align the triad coordinate system with the anatomical coordinate system for the scapula in order to calculate joint angles of the scapula during dynamic trials. This allowed for the points of the scapula to be located during the dynamic trials even though the anatomical markers were not present. Please refer to the diagram of the triad in Figure 8 for the following equations.

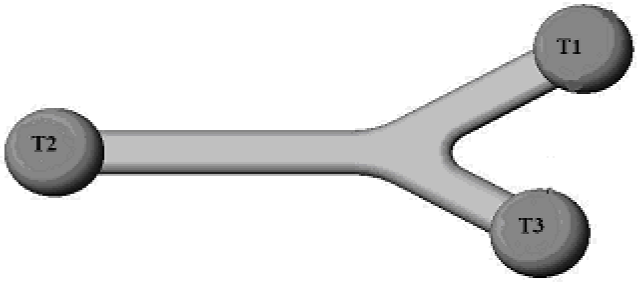

Figure 8. Scapula Triad

The y-axis of the triad coordinate system (Tr_Y) was a unit vector pointing from T_3 to T_1.

$$\mathrm{Tr}_Y = \frac{(T_1 - T_3)}{\|T_1 - T_3\|}$$

Equation 16.

The z-axis of the triad coordinate system (Tr_Z) was a unit vector pointing in the superior direction perpendicular to the plane formed by triad markers T_1, T_2, and T_3. This was found by taking the cross product of Tr_Y and a unit vector pointing from triad marker T_3 to triad marker T_2.

$$\mathrm{Tr}_Z = \frac{Tr_Y \times (T_2 - T_3)}{\|Tr_Y \times (T_2 - T_3)\|}$$

Equation 17.

Finally, the x-axis of the triad coordinate system (Tr_X) was a unit vector pointing in the anterior direction and was the cross product of Tr_Y and Tr_Z.

$$Tr_X = \frac{Tr_Y \times Tr_Z}{\left\| Tr_Y \times Tr_Z \right\|}$$

Equation 18.

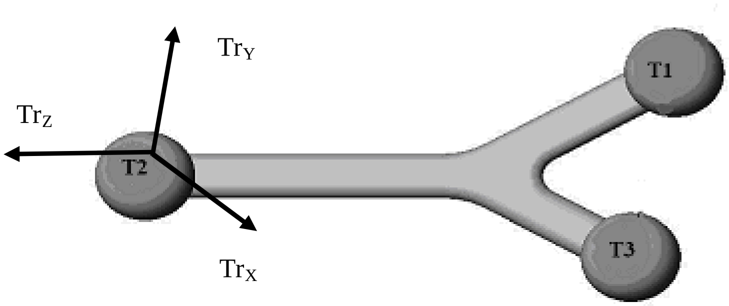

Figure 9. Triad Coordinate System

The first step in aligning the triad coordinate system with the anatomical coordinate system of the scapula was to establish the unit vector matrix for the triad [U_{TRI}].

$$[U_{TRI}] = [Tr_X' \;\; Tr_Y' \;\; Tr_Z']$$

Equation 19.

Next, the scapula anatomical markers were located using data from the static trial. Anatomical marker offsets for AA, TS, and AI (S_1, S_2, and S_3, respectively) represent the distance from the anatomical marker to the origin of the triad (T_2). Once these anatomical markers were located, they were then rotated into the global coordinate system (U_G).

- Location of AA

$$\text{AA} = \left(T_2 * \left(U_G \bullet U_{TRI}\right)\right) + S_1$$

Equation 20.

- Location of TS

$$\text{TS} = \left(T_2 * \left(U_G \bullet U_{TRI}\right)\right) + S_2$$

Equation 21.

- Location of AI

$$\text{AI} = \left(T_2 * \left(U_G \bullet U_{TRI}\right)\right) + S_3$$

Equation 22.

Based on data from the triad (see equations 20-22) a new scapula coordinate system was created with its origin at AA. The y-axis of the scapula coordinate system (S_Y) was a unit vector pointing from AA to TS.

$$S_Y = \frac{(TS - AA)}{\|TS - AA\|}$$

Equation 23.

The x-axis of the scapula coordinate system (S_X) was a unit vector pointing in the anterior direction and perpendicular to the plane formed by scapula markers AA, TS, and AI. This was found by taking the cross product of a unit vector pointing from AA to AI and S_Y .

$$S_X = \frac{(AI - AA) \times S_Y}{\left\| (AI - AA) \times S_Y \right\|}$$

Equation 24.

Finally, the z-axis of the scapula coordinate system (S_Z) was a unit vector pointing in the superior direction and was the cross product of S_X and S_Y.

$$S_Z = \frac{S_X \times S_Y}{\left\| S_X \times S_Y \right\|}$$

Equation 25.

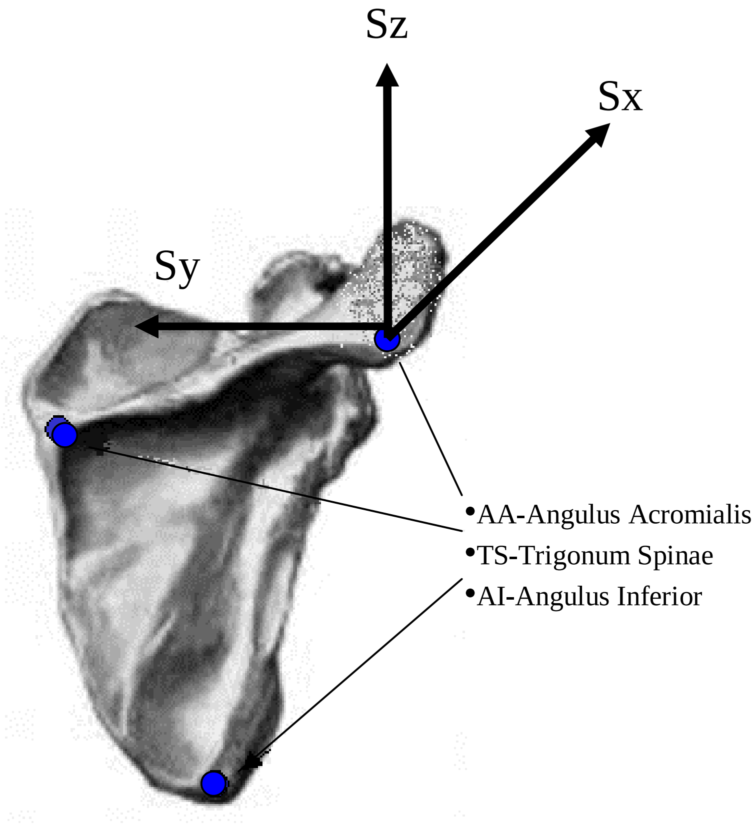

Figure 10. Scapula Coordinate System

Rotation Sequences for Each Body Segment

In order to calculate the segment angles of interest, rotation matrices for each segment were created.

- Head rotation matrix

$$[R_H] = [H_X{'} \;\; H_Y{'} \;\; H_Z{'}]$$

Equation 26.

- Thorax rotation matrix

$$[R_T] = [T_X{'} \;\; T_Y{'} \;\; T_Z{'}]$$

Equation 27.

- Pelvis rotation matrix

$$[R_P] = [P_X{'} \;\; P_Y{'} \;\; P_Z{'}]$$

Equation 28.

- Scapula rotation matrix

$$[R_S] = [S_X{'} \;\; S_Y{'} \;\; S_Z{'}]$$

Equation 29.

Euler angles were then calculated in order to quantify the orientation of one segment relative to another segment. The orientation of the pelvis (R_{Pelvis}) was defined relative to the global coordinate system and was the product of the inverse of the pelvis rotation matrix [R_P] and the global coordinate system matrix [U_G].

$$\mathrm{R_{Pelvis}} = inv[R_P] * [U_G]$$

Equation 30.

The orientation of the torso ($\mathrm{R_{Torso}}$) was defined relative to the pelvis ($\mathrm{R_{Pelvis}}$) and was the product of the inverse of the torso rotation matric [$\mathrm{R_T}$] and the pelvis rotation matrix [$\mathrm{R_P}$].

$$\mathrm{R_{Torsos}} = inv[R_T] * [R_P]$$

Equation 31.

The orientation of the scapula ($\mathrm{R_{Scap}}$) was defined relative to the torso ($\mathrm{R_{Torso}}$) and was the product of the inverse of the scapula rotation matrix [$\mathrm{R_S}$] and the torso rotation matrix [$\mathrm{R_T}$].

$$\mathrm{R_{Scap}} = inv[R_S] * [R_T]$$

Equation 32.

Finally, the orientation of the head ($\mathrm{R_{Head}}$) was defined relative to the torso ($\mathrm{R_{Torso}}$) and was the product of the inverse of the head rotation matrix [$\mathrm{R_H}$] and torso rotation matrix [$\mathrm{R_T}$].

$$\mathrm{R_{Head}} = inv[R_H] * [R_T]$$

Equation 33.

In this study, the sagittal plane was the primary plane of movement (movement about the y-axis). Therefore, rotations were conducted in the following order to ensure accuracy in the calculations of movement occurring in the sagittal plane: Y-axis, X-axis, Z-axis. Euler angles for each segment were extracted from the unit vector matrix associated with that segment using the following equations

- Movement about the Y-axis

$$\alpha = \tan^{-1}\left(\frac{-R_{32}}{R_{33}}\right)$$

Equation 34.

- Movement about the X-axis

$$\beta = \sin^{-1}\left(R_{31}\right)$$

Equation 35.

- Movement about the Z-axis

$$\gamma = \tan^{-1}\left(\frac{-R_{21}}{R_{11}}\right)$$

Equation 36.

For the head and thorax α, β, and γ correspond to flexion/extension, lateral flexion, and rotation, respectively. For the pelvis, α, β, and γ correspond to tilt, lateral flexion and internal/external rotation, respectively. For the scapula, α, β, and γ correspond to tilt, upward rotation, and protraction/retraction, respectively.

Electromyography

Postural alterations due to heavy breast tissue may cause strain on the cervico-thoracic muscles, thus inducing muscle weakness of these important upper body postural muscles. In order to examine the effects of excess breast tissue mass on cervico-thoracic muscle activation, electromyographic data of the muscles associated with musculoskeletal pain in the neck, back and shoulder regions was obtained using a wireless surface electromyography (sEMG) system (BTS Engineering FreeEMG, 1000 Hz). This system works by using wireless technology to detect muscle activation via individual sensors placed over the muscle of interest. This section will address the placement of the electrodes, processing of the raw signals, and the quantification of the amplitude of muscle activation for all five muscles of interest as a percentage of MVC.

Electrode Placement

Prior to placement of individual EMG sensors on the subject, the subject's skin was abraded and cleaned with alcohol in order to reduce skin impedance. Pre-gelled silver-silver chloride bipolar electrodes with the wireless EMG sensors attached were then placed on each of the five muscles of interest according to the methods described by Cram (Table 1 below and Figures B1-B5 in Appendix B) [41].

Table 1. Surface Electrode Placement

Muscle	**Placement**
Midcervical (C-4) Paraspinal	Placed two centimeters away from the spine and parallel with the muscle fibers over the muscle belly at approximately the fourth cervical vertebrae (C-4)
Upper Trapezius	Placed running parallel with the muscle fibers along the ridge of the shoulder, slightly lateral to and onehalf the distance between the seventh cervical vertebrae (C-7) and the acromion
Lower Trapezius	Placed at an oblique angle, approximately five centimeters down from the scapular spine and placed next to the medial edge of the scapula at a 55-degree angle
Serratus Anterior	Placed horizontally just below the axillary area, at the level of the inferior tip of the scapula, and just medial of the latissimus dorsi.
Low Back (Erector Spinae)	Placed parallel to the spine, approximately two centimeters from the spine and placed over the muscle mass. Subjects were in a slight forward flexion for electrode placement.

Maximum Voluntary Contraction Protocol

To define the maximal exertion of the muscles of interest, a maximum voluntary contraction (MVC) was obtained for each muscle. The exercise chosen to obtain the MVC for each muscle of interest was the superman exercise, in which the chest, arms, and legs are simultaneously raised as high off the table as possible (Figure 11).
Each subject was instructed to lie in a prone position on an examination table with her arms stretched out in front. The subject was then strapped to the table with one strap across the top of the shoulders and a second strap just above the knees in order to provide resistance to the subject during the exercise. Each subject performed five repetitions of the MVC and the average maximum EMG signal during the contraction was used to normalize the tasks of daily living EMG signals.

Figure 11. The Superman Exercise

Initial Signal Processing

EMG data was obtained via surface electromyography. EMG signals from each muscle were sampled at 1000 Hz via individual EMG sensors placed over the muscles of the neck, upper thorax, and low back (described above in Table 1) during each activity of daily living (described below in the experimental protocol section). Data was rectified and smoothed using a root mean square algorithm with a 20-ms moving window and normalized to the MVC as a percentage of effort.

To find the percent muscle activation of each of the five muscles of interest, the peak EMG signal for each muscle was found using custom Matlab software. This maximum peak was used to establish a ratio of upper body posture muscle activation to MVC muscle activation, resulting in a ratio of percent effort ranging from 0-100%.

$$\text{\% Muscle Activation} = \left[\frac{A_{muscle}}{MVC_{muscle}} \right] \times 100$$

Equation 37.

In the above equation, A_{muscle} represents the peak amplitude of the individual muscle activation during each task of daily living, and MVC_{muscle} represents the peak amplitude of the individual muscle activations during the MVC exercise.

Health-Related Quality of Life

Women who present with breast hypertrophy typically exhibit poorer scores on health-related quality of life instruments [2, 14, 21, 28, 29]. Although the main focus of this study is the biomechanical effects of breast hypertrophy on the spine and cervico-thoracic muscle activation, it was important to assess each subject's health-related quality of life status in order to establish relationships between the biomechanical data from this study and the health-related quality of life data presented in previous studies.

Health-Measure Instrument

The Breast Related Symptoms Questionnaire (BRSQ) was administered to each subject in order to determine the severity of the pain associated with breast hypertrophy each subject is experiencing (See Appendix A). The BRSQ is a 13 item condition specific instrument developed by Kerrigan et al in 2001 in order to systematically quantify breast-specific symptoms [21]. A breast symptom summary score (BSS) was computed by averaging the item scores and linearly transforming the average to a 0-to-100 scale. For this instrument, higher summary scores correspond to fewer and less severe systems. This instrument has undergone test-retest reliability and has face validity [20, 21].

Experimental Protocol

All subjects for this study were women over the age of 18 who have never undergone or been approved for breast augmentation surgery (N=26). All subjects were recruited from the general student, faculty and staff population at Boise State University. Participation in this study was strictly voluntary, and subjects were free to discontinue their participation in this study at any time during the data collection session. This study was approved by the Institutional Review Board at Boise State University prior to initiation of subject recruitment.

All testing was conducted at the Intermountain Orthopaedics Sports Medicine and Biomechanics Research Laboratory on the campus of Boise State University in Boise, Idaho. Upon arrival to the lab, each subject read and signed the informed consent document prior to participation in the study and was given a copy for their records.

Once the informed consent had been signed, each subject completed the Breast Related Symptoms Questionnaire. Subjects were allowed to fill out this questionnaire independently with the principal investigator present in order to answer any questions that the subject may have had.

Following completion of the Breast Related Symptoms Questionnaire, descriptive data for each subject was obtained for each individual by the principal investigator and a research assistant. The data obtained included: age, height, weight, self-reported bra cup size, type of bra worn for testing, and sternal notch to nipple distance. Each subject's height (meters) and weight (kilograms) was used to calculate her Body Mass Index (BMI) using the following formula:

$$\text{BMI} = \frac{weight(kg)}{height(m)^2}$$

Equation 38.

Once all the descriptive data had been obtained, each subject was prepared with spherical surface markers and EMG electrodes for biomechanical data collection (as described above in kinematic and muscle activation section, respectively). Subjects were asked to perform testing while wearing a tank top so that surface markers and sEMG electrodes could be placed directly on the skin surface when appropriate (See Appendix C for pictures of complete subject setup). Once all the surface markers and sEMG electrodes were in place, a static image of the subject was obtained using the VICON optical motion capture system. Once the static image was obtained, the anatomically based markers on the scapula were removed (as described above in the Kinematics section and seen below in Figures 12 and 13).

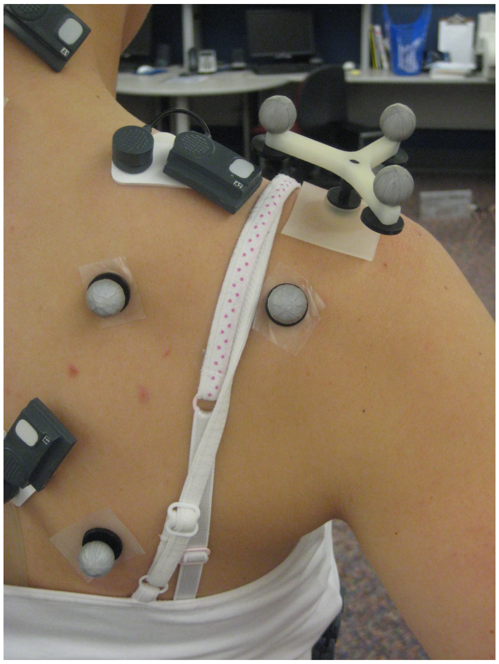

Figure 12. Scapula Marker Set up during the Static Image

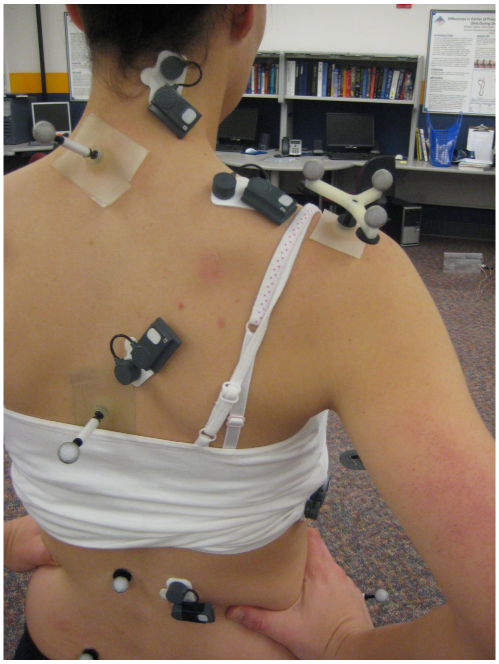

Figure 13. Anatomically Based Scapula Markers Removed

In order to get an idea of the kinematics of the upper body and the amount of muscle activation each subject used while in their natural standing postural alignment, static posture measurements were obtained before and after the four tasks of daily living had been completed. To obtain static posture, subjects were instructed to place their hands on their hips and adopt a comfortable and natural standing position as if no one was watching them [25]. Once in this position subjects were instructed to remain as still as possible and to count backwards from fifty. Static positions of each of the surface markers, and static values for muscle activation were captured for two 3-5 second intervals both before and after the four tasks of daily living had been completed (Figure 14).

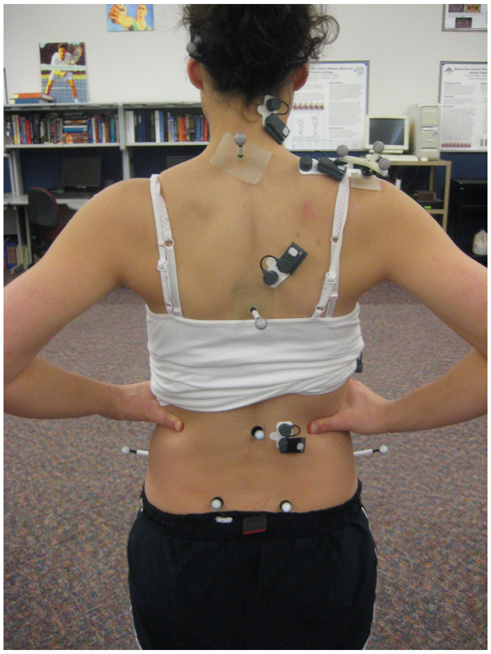

Figure 14. Standing Position of Subject during Static Posture Measurements

Kinematics of the upper body as well as muscle activation was measured while the subject performed four different tasks of daily living. Each subject performed a series of 5-10 trials of each of the four tasks of daily living with approximately 30-45 seconds of rest in between each trial and 1-2 minutes of rest between each task. The tasks were performed in random order and included:

- Picking a pencil off the ground: Subjects were instructed to begin the exercise with their hands on their hips and reach down to pick up a pencil off the floor as they normally would as if they had dropped it. Subjects were also instructed to place their hands back on their hips following the completion of the task.

- Sitting down and standing up from a stool: Subjects were asked to place their hands on their hips throughout the duration of the task as they sat down and then stood up from a stool.
- Stepping on and off a six inch tall platform: Subjects were instructed to step on and off the platform leading with their right leg and keeping their hands on their hips throughout the duration of the task.
- Lifting a milk jug filled with 9.75 pounds of sand overhead: Subjects were instructed to begin the exercise with their hands on their hips, and then reach down and pick up the weighted milk jug with their right hand. Once they had picked up the jug, each subject used their left hand to help guide the jug to a point overhead, and then lowered the jug back down. Subjects were also instructed to place their hands back on their hips following the completion of the exercise.

Once all the trials had been completed, the electrodes and surface markers were removed by the principal investigator and research assistants.

Statistics

All statistical analysis was completed using Microsoft Excel 2003 for Windows. To compare muscle activation and kinematic variables across the four tasks of daily living, and BSS scores between subjects, a two-tailed independent t-test was performed for each dependent variable of interest. Power analysis was performed for each dependent variable's t-test using an online statistics toolkit (provided by DSS Research) in order to get an idea of the probability of making a type II error (β). For the purposes of this study, *p* values less than 0.05 were considered to be statistically significant.

Due to the small size of the subject population and the possibility of slight variations in how each subject chose to perform each task of daily living, an outlier test was performed on all data collected in order to account for any extreme skews in the distribution. In order to identify possible outliers in the data set, the interquartile range (IQR) was computed for each dependent variable. Data points found to be three times the IQR less than the first quartile or three times the IQR greater than the third quartile were considered outliers and were not included in the final data analysis. Data points associated with muscle activation were also excluded from the final data if %MVC values during tasks of daily living produced negative results since that would indicate that the subject used greater than their maximum effort to complete the given task.

RESULTS

This section contains all the results from the data collection and analysis previously described. This includes demographic information of the participating subjects and comparison of breast summary scores (BSS), muscle activation and upper body kinematics between normal control subjects and breast hypertrophy subjects. A total of 26 subjects participated in this study. However, only 22 subjects were used in the final analysis due to insufficient data from four participants. All subjects were recruited from the female population of students and faculty at Boise State University and had no history of breast augmentation surgery.

Three subjects from the normal control group were not included in the lift trial results and one subject from the normal control group was not included in the step up trial results because the electromyography data did not match up with the kinematic data. As a result, the normal control group data set consisted of 608 data points and the hypertrophy group data set consisted of 540 data points before statistical analysis took place.

As mentioned above in the methods section, any negative %MVC values and extreme outliers were removed from the data sets. Out of 608 data points for the normal group, fourteen data points were removed for being negative %MVC values and fifteen data points were removed for being extreme outliers for a total of 4.76% of points removed from the normal control group data set. Out of 540 data points for the hypertrophy group, twelve data points were removed for being negative %MVC values, and fifteen data points were removed for being extreme outliers for a total of 5.00% of points removed from the hypertophy group data set.

Demographics

Of the 22 subjects analyzed, 12 were in the normal control group (self-reported bra cup sizes A – C), and 10 were in the hypertrophy group (self-reported bra cup size > D). Distribution of self-reported bra cup sizes is shown in Figure 15. The average age of the normal control and hypertrophy subjects was 24.4 (±4.1 yrs, range 20-34), and 26.1 (±6.7 yrs, range 21-40), respectively.

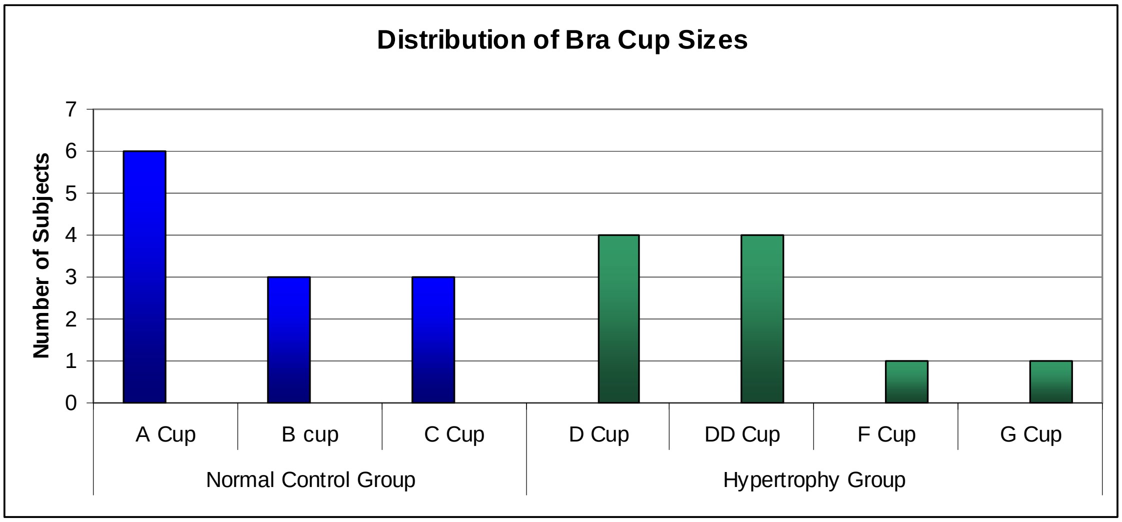

Figure 15. Subject Distribution by Group and Bra Cup Size

Subject demographics for the two groups are given in Table 2. Statistical analysis of the subject demographics revealed significant differences in height (p=0.003), BMI (p=0.009), left SNTND (p=0.004), and right SNTND (p=0.000) between the two groups.

Table 2. Subject Demographics

		Normal Control	**Hypertrophy**	**p value**	**Power**
Height (m)	Mean	1.73	1.64	0.003*	0.778
	Std Dev	±0.10	±0.44		
Weight (kg)	Mean	71.00	77.60	0.322	0.299
	Std Dev	±10.0	±11.34		
BMI (kg/m^2)	Mean	23.92	28.84	0.009*	0.873
	Std Dev	±3.62	±3.78		
Left SNTND	Mean	15.23	18.65	0.004*	0.968
	Std Dev	±1.23	±2.60		
Right SNTND	Mean	14.75	18.36	0.005*	0.992
	Std Dev	±1.11	±2.41		
*Statistically significant p<0.05					

BRSQ Scores

The Breast Related Symptoms Questionnaire (BRSQ) is a validated instrument used to evaluate the severity of breast-related symptoms. The BSS is a linearly transformed average of the responses given on the BRSQ, and is used to quantify the burdens of breast hypertrophy with lower scores being indicative of an increase in the severity of breast-related symptoms. Data from the BRSQ for both subject groups is shown in Table 3. Women in the normal control group scored significantly higher (p=0.005) on the BRSQ, indicating a lesser severity of breast-related symptoms.

Table 3. BRSQ Scores

Group	BSS	Standard Deviation	Power
Normal Control	99.13	1.32	0.993
Hypertrophy	71.54	19.75	
*Statistically significant $p<0.05$			

Kinematic Results

Upper body kinematics of the head, thorax, pelvis and scapula were quantified in order to get a better understanding of the effect of breast size on the musculoskeletal system. Specifically, head flexion, torso flexion and extension, lateral torso extension, scapular protraction, scapular upward rotation, and pelvic tilt were analyzed for static trials and for each task of daily living.

For analysis purposes, two static trials from the beginning of the data collection and two static trials from the end of the data collection were used to create an “average static posture” for each subject. Subject movement was normalized to static posture by subtracting the “average static posture” from the average maximum kinematic values for each task, thus allowing movement variables between subjects to be compared.

Static Posture

Static trial data was collected before and after the four tasks of daily living had been completed. Group averages of average static posture measurements for normal control subjects and hypertrophy subjects are shown in Figure 16.

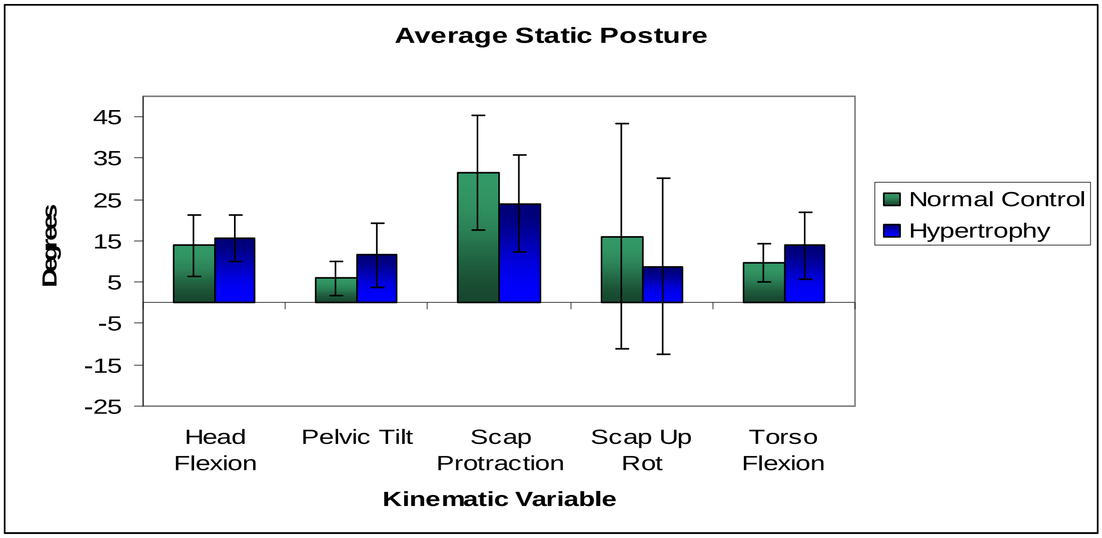

Figure 16. Group Average Static Posture Variables

Average static posture values for both groups are shown in Table 4. Statistical analysis revealed no significant differences in average static posture between groups. However, it is important to note that anterior pelvic tilt is approaching significance (p=0.098) during static posture measurements.

Table 4. Average Static Posture

Group		**Head Flexion (+)**	**Anterior Pelvic Tilt (+)**	**Scapular Protraction (+)**	**Scapular upward rotation (+)**	**Torso flexion (+)**
Normal Control	Mean	13.87°	5.95 °	31.58 °	16.10 °	9.64°
	Std Dev	± 7.45 °	± 4.19 °	± 13.85°	± 27.18 °	± 4.63°
Hypertrophy	Mean	15.63 °	11.51 °	23.94 °	8.85°	13.85°
	Std Dev	± 5.70 °	± 7.73 °	± 11.74°	± 21.23 °	± 8.04°
p-value		0.839	0.097	0.13	0.354	0.23
Power		0.097	0.532	0.288	0.108	0.311

Head Flexion

Head flexion data for the pencil, sit, step up, and lift tasks for both normal control and hypertrophy subjects are shown in Table 5. Normal control subjects appear to present with more head flexion while performing tasks of daily living. However, statistical analysis provided no significant differences between the two groups during these tasks.

Table 5. Head Flexion During Tasks of Daily Living

Task		Normal Control	Hypertrophy	p value	Power
Pencil	Mean	35.70°	30.18°	0.484	0.244
	Std Dev	±11.16°	±9.32°		
Sit	Mean	20.48°	15.11°	0.206	0.240
	Std Dev	±6.55°	±12.17°		
Step Up	Mean	5.29°	4.59°	0.741	0.059
	Std Dev	±7.21°	±4.81°		
Lift	Mean	26.18°	16.21°	0.325	0.576
	Std Dev	±14.02°	±7.13°		

Pelvic Tilt

Data regarding the average amount of pelvic tilt occurring during the four tasks of daily living is provided in Table 6. For 3 of the 4 activities of daily living, hypertrophy subjects appear to present with more anterior pelvic tilt. Despite visual differences, statistical analysis showed no significant differences between the two groups during the four tasks of daily living. However, the difference in pelvic tilt during the sit exercise appears to be approaching significance (p = 0.091).

Table 6. Pelvic Tilt During Tasks of Daily Living

Task		Normal Control	Hypertrophy	p value	Power
Pencil	Mean	27.18º	28.27º	0.296	0.059
	Std Dev	±3.30º	±12.15º		
Sit	Mean	11.59º	17.11º	0.091	0.449
	Std Dev	±6.10º	±7.74º		
Step Up	Mean	8.01º	10.63º	0.123	0.311
	Std Dev	±3.09º	±4.90º		
Lift	Mean	8.82º	6.29º	0.527	0.174
	Std Dev	±4.12º	±6.92º		

Scapular Movements

The main movement of interest for the scapula was scapular protraction, except for in the lift task in which upward rotation of the scapula was examined. Data for the scapula movement during the four tasks of daily living is provided in Table 7. Statistical analysis of the movements of the scapula during all four tasks of daily living showed no significant differences between the normal control group and the hypertrophy group.

Table 7. Scapula Movement During Tasks of Daily Living

Task		Normal Control	Hypertrophy	p value	Power
Pencil	Mean	22.99º	22.15º	0.914	0.051
	Std Dev	±15.99º	±24.30º		
Sit	Mean	6.22º	8.40º	0.317	0.057
	Std Dev	±7.70º	±4.87º		
Step Up	Mean	10.19º	8.09º	0.545	0.114
	Std Dev	±7.93º	±5.39º		
Lift#	Mean	7.21º	4.53º	0.450	0.199
	Std Dev	±7.03º	±4.09º		

#Scapular Upward Rotation measured during lift trials

Torso Flexion

Torso flexion was analyzed across all four tasks of daily living, except for in the lift task which torso extension was the variable of interest. During the lift task, lateral torso flexion (Lift 2) was also analyzed in order to investigate the role of the spine in the biomechanics of the shoulder during an overhead activity (positive values represent flexion of the spine towards the left side of the body). Average torso flexion values for both subject groups during the four tasks of daily living are shown in Table 8. Visual analysis of the data indicates that normal control subjects exhibited greater amounts of torso flexion during pencil, sit, and step up tasks. Statistical analysis of torso flexion showed significant differences in the average amount of torso flexion during the pencil and step up tasks (p= 0.055 and 0.001, respectively). Conversely, hypertrophy subjects exhibited slightly greater mounts of torso extension and lateral torso flexion during the lift tasks. However, neither of these differences seen was statistically significant.

Table 8. Torso Movement During Tasks of Daily Living

Task		Normal Control	Hypertrophy	p value	Power
Pencil	Mean	53.40°	40.76°	0.055*	0.675
	Std Dev	±10.87°	±13.25°		
Sit	Mean	19.31°	14.87°	0.093	0.223
	Std Dev	±7.71°	±9.40°		
Step Up	Mean	15.21°	6.04°	0.001*	0.993
	Std Dev	±4.72°	±4.99°		
Lift#	Mean	6.12°	10.14°	0.190	0.349
	Std Dev	±3.11°	±7.59°		
Lift 2##	Mean	1.84°	1.88°	0.410	0.050
	Std Dev	±1.62°	±1.91°		

#Values represent amount of torso extension during lift trials

##Values represent lateral torso flexion during lift trials

*Statistically significant $p<0.05$

Muscle Activation

The amount of muscle activation (expressed as %MVC) exhibited by a particular muscle provides information about the amount of work the muscle of interest is performing. It has been hypothesized that pain in the neck, back and shoulders symptomatic of breast hypertrophy may be due to increased tension (activation) of the cervico-thoracic muscles.

This study specifically examined muscle activation of the Midcervical (C-4) paraspinal, upper trapezius, lower trapezius, serratus anterior, and the low back (Erector Spinae) during static posture trials and tasks of daily living. All electromyography data matches up with the movement trials used in the kinematic analysis.

For analysis purposes, two static trials from the beginning of the data collection and two static trials from the end of the data collection were used to create "average static muscle activation" for each subject. Subject movement was normalized to static posture by subtracting the "average static muscle activation" from the average muscle activation values for each task, thus muscle activation between subjects to be compared.

Static Posture

Data was collected for static trials before and after the tasks of daily living were completed. The muscle activation of the five muscles of interest during static posture trials is shown in Table 9. Group averages of average static posture measurements for normal control subjects and hypertrophy subjects are shown in Figure 17.

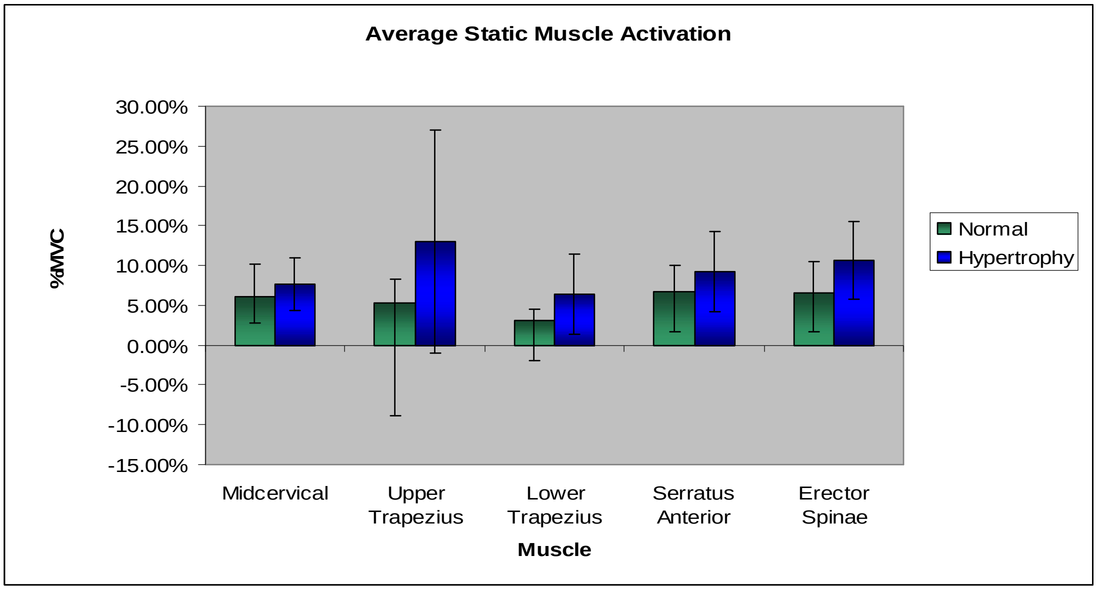

Figure 17. Group Averages for Muscle Activation

Table 9. Static Muscle Activation

Muscle		**Normal Control (%MVC)**	**Hypertrophy (%MVC)**	**p value**	**Power**
Midcervical	Mean	6.10%	7.62%	0.582	0.170
	Std Dev	±4.03%	±3.30%		
Upper Trapezius	Mean	5.23%	13.04%	0.123	0.407
	Std Dev	±3.11%	±14.03%		
Lower Trapezius	Mean	3.12%	6.35%	0.051*	0.502
	Std Dev	±1.39%	±5.04%		
Serratus Anterior	Mean	6.64%	9.23%	0.075	0.286
	Std Dev	±3.39%	±5.00%		
Erector Spinae	Mean	6.52%	10.62%	0.115	0.576
	Std Dev	±3.90%	±4.86%		
*Statistically significant p<0.05					

Analysis of static muscle activation shows that hypertrophy subjects exhibited higher percentages of muscle activation during static posture trials. Statistical analysis indicates a significant difference in the level of muscle activation of the lower trapezius (p = 0.051).

Pencil Task

Average muscle activation values for the pencil task are shown in Table 10. Hypertrophy subjects exhibited greater amounts of muscle activation for all five muscles during the pencil task. However, statistical analysis showed no significant differences in the levels of muscle activation between the two subject groups during this task.

However, the difference in lower trapezius muscle activation between groups appears to be approaching significance.

Table 10. Muscle Activation during the Pencil Task

Muscle		**Normal Control (%MVC)**	**Hypertrophy (%MVC)**	**p value**	**Power**
Midcervical	Mean	3.12%	7.91%	0.168	0.375
	Std Dev	±1.85%	±9.08%		
Upper Trapezius	Mean	8.94%	12.75%	0.741	0.097
	Std Dev	±9.88%	±16.73%		
Lower Trapezius	Mean	2.54%	3.24%	0.071	0.083
	Std Dev	±2.59%	±3.40%		
Serratus Anterior	Mean	2.50%	3.39%	0.765	0.132
	Std Dev	±2.81%	±2.21%		
Erector Spinae	Mean	2.04%	2.35%	0.687	0.071
	Std Dev	±1.09%	±2.08%		
*Statistically significant p<0.05					

Sit Task

Muscle activation levels of the five muscles of interest during the sit task are provided in Table 11. Hypertrophy subjects exhibited greater muscle activation in all muscles except the upper trapezius during the sit task. However, statistical analysis revealed no significant differences between the %MVC means of the normal control and hypertrophy group for this task.

Table 11. Muscle Activation during the Sit Task

Muscle		**Normal Control (%MVC)**	**Hypertrophy (%MVC)**	**p value**	**Power**
Midcervical	Mean	3.20%	3.39%	0.738	0.053
	Std Dev	±3.25%	±2.71%		
Upper Trapezius	Mean	5.75%	2.97%	0.114	0.373
	Std Dev	±5.43%	±2.06%		
Lower Trapezius	Mean	0.91%	1.24%	0.578	0.290
	Std Dev	±0.57%	±0.53%		
Serratus Anterior	Mean	2.71%	4.37%	0.426	0.239
	Std Dev	±2.63%	±3.45%		
Erector Spinae	Mean	1.24%	1.64%	0.410	0.284
	Std Dev	±0.55%	±0.76%		
*Statistically significant p<0.05					

Step Up

Muscle activation levels of the five muscles of interest during the step up task are provided in Table 12. Hypertrophy subjects exhibited greater levels of muscle activation in the midcervical, lower trapezius, serratus anterior, and erector spinae during the step up task. However, statistical analysis yielded no significant differences between the %MVC means of the normal control and hypertrophy groups for this task.

Table 12. Muscle Activation during the Step Up Task

Muscle		**Normal Control (%MVC)**	**Hypertrophy (%MVC)**	**p value**	**Power**
Midcervical	Mean	4.42%	5.95%	0.815	0.116
	Std Dev	±4.36%	±5.11%		
Upper Trapezius	Mean	5.12%	2.46%	0.139	0.776
	Std Dev	±3.09%	±0.95%		
Lower Trapezius	Mean	0.96%	5.94%	0.104	0.544
	Std Dev	±0.55%	±0.55%		
Serratus Anterior	Mean	3.75%	3.95%	0.577	0.054
	Std Dev	±2.44%	±2.74%		
Erector Spinae	Mean	1.99%	3.72%	0.239	0.589
	Std Dev	±1.00%	±2.33%		
*Statistically significant p<0.05					

Lift Task

Muscle activation levels of the five muscles of interest during the step up task are provided in Table 13. Statistical analysis of the muscle activation levels during the lift task showed no significant differences between the two groups. However, it is important to note that hypertrophy subjects exhibited greater muscle activation in the lower trapezius, serratus anterior and erector spinae than the normal control subjects while performing this task

Table 13. Muscle Activation during the Lift Task

Muscle		**Normal Control (%MVC)**	**Hypertrophy (%MVC)**	**p value**	**Power**
Midcervical	Mean	8.62%	6.65%	0.315	0.175
	Std Dev	±4.72%	±4.92%		
Upper Trapezius	Mean	27.57%	16.27%	0.241	0.253
	Std Dev	±26.19%	±13.86%		
Lower Trapezius	Mean	3.32%	5.12%	0.365	0.139
	Std Dev	±1.96%	±6.37%		
Serratus Anterior	Mean	4.69%	6.33%	0.590	0.163
	Std Dev	±2.80%	±4.70%		
Erector Spinae	Mean	4.79%	5.22%	0.481	0.058
	Std Dev	±2.86%	±4.30%		
*Statistically significant $p<0.05$					

DISCUSSION

The purpose of this study was to investigate biomechanical differences in the upper body of women with larger breast sizes in order to provide evidence of the musculoskeletal burdens of breast hypertrophy. In this study, women were divided into two groups based on self-reported bra cup size in order to investigate differences in breast-related symptoms, and differences in upper body kinematics and muscle activation during tasks of daily living.

BRSQ Scores

While there is not an exact definition of breast hypertrophy, it is widely accepted as a characterized increase in the volume and weight of breast tissue beyond normal proportions. Normal breast size is defined as a self-reported bra cup size of C or smaller [1, 20]. Previous studies have concluded that women who present with breast hypertrophy typically exhibit poorer scores on health-related quality of life instruments [2, 14, 21, 28, 29].

Results from the analysis of the BRSQ in this study found that women in the normal control group (defined as self-reported bra cup size of C or smaller) scored significantly higher on the BRSQ than women in the hypertrophy group, indicating lesser severity of breast related symptoms. These results are consistent with results from the BRAVO study by Kerrigan et al in which it was found that only 2% of women with normal breast sizes experience 2 or more breast related symptoms all or most of the time, and 87.6% of women presenting for surgical correction of breast hypertrophy list at least two out of seven physical symptoms occurring all or most of the time [1, 20].

Static Posture

Women with breast hypertrophy generally present with numerous breast related symptoms relating to the skeletal system including neck strain, headache, and aching shoulders [8]. It is postulated that these symptoms are a direct result of functional impairment caused on the musculoskeletal system due to size and position of hypertrophic breasts. However, examination of average static postures for the two subject groups in this study showed no significant differences in the skeletal alignment of the individuals in these groups.

Despite a lack of significant differences in static posture alignment found in this study, it is important to note that the hypertrophy group did present with greater amounts of cervical lordosis (head flexion), forward shoulder position (shoulder protraction), thoracic kyphosis (torso flexion) and lumbar lordosis (pelvic tilt) than women in the normal control group. These findings are supported by postulations by Letterman et al about the structural basis for breast related symptoms related to the skeletal system in which it is stated that the above structural changes are a direct result of a change in the body’s center of gravity to compensate for the weight and position of hypertrophic breasts [8].

Of increasing interest is the approaching significance of the difference in the degree of anterior pelvic tilt during the static condition. Women in the hypertrophy group demonstrated values of pelvic tilt almost double the value of women in the normal control group. Increases in anterior pelvic tilt lead to an increase in lumbar lordosis [42]. This increase in lumbar lordosis in the hypertrophy group is consistent to postulations by Letterman et al in which it was stated that increased lumbar lordosis is a compensatory mechanism used by women with breast hypertrophy to help keep the body in an upright position [8].

Kinematics during Tasks of Daily Living

Changes in the body's center of gravity may lead to secondary effects on the functional mobility of the musculoskeletal system. However, results from this study demonstrated few significant differences in the musculoskeletal mechanics of women with large breasts when compared to women with normal breast sizes. Torso flexion exhibited the most consistent differences between the two subject populations, with normal control subjects exhibiting significantly increased torso flexion during the step up task, as well as increased torso flexion during the pencil and sit tasks. These results are inconsistent with findings in static posture trials where women with hypertrophic breasts exhibited increased (although not significant) torso flexion, indicating that women with hypertrophic breasts may compensate for baseline alterations of the spine in other ways, such as increases in muscle activation, while performing tasks of daily living.

Muscle Activation during Tasks of Daily Living

Interestingly, these kinematic differences seen in the torso of normal control subjects were not accompanied by significant differences in muscle activation. Despite having increased torso flexion during pencil, step up, and sit tasks, normal control subjects had muscle activation values less than or similar to the muscle activation values for the women with breast hypertrophy during the same tasks.

The pencil task was the only activity that provided a difference in muscle activity that was approaching significance. As mentioned before, the size and weight of hypertrophic breasts may cause a change in the location of the body's center of gravity. As a subject bends down to pick up a pencil, the size and weight of the breasts may pull the head further away from the center of gravity than it already was. As the distance from the head to the center of gravity increases, the greater the amount of midcervical muscle tension required to sustain the weight of the head in this position becomes [8]. In the pencil task, women with hypertrophic breast exhibited 7.91%MVC muscle activation compared to only 3.12%MVC muscle activation in the midcervical muscles of normal control subjects.

While bending down to pick up a pencil, it appears that women with hypertrophic breasts may compensate for increased midcervical activation by activating the lower trapezius muscles in an attempt to keep the head and neck in a more upright position. Women in the hypertrophy group exhibited 3.23%MVC muscle activation in the lower trapezius while women in the normal control exhibited on 2.53%MVC muscle activation during the pencil task. While this difference is only approaching significance, it may provide important insight to the compensatory mechanisms used by the musculoskeletal system to compensate for hypertrophic breasts.

Posture and Muscle Activation Relationship

While the muscle activation differences between the two groups were not significant, higher levels of muscle activation exhibited by hypertrophy subjects during both static posture and tasks of daily living may be related to the altered static postural alignment exhibited by these same subjects. An example of this relationship can be seen in the lower amount of low back (erector spinae) activation in the normal control group during static trials. Normal control group subjects exhibited less anterior pelvic tilt, resulting in a lesser degree of lumbar lordosis. This flattening out of the lumbar lordosis affects the thoracic spine, which extends slightly to adjust the center of gravity of the trunk so that the energy expenditure, in terms of muscle exertion (activation), is minimized [42].

As stated earlier in this document, posturally induced muscular weakness, or "stretch weakness," has been defined as the effect on muscles of remaining in a lengthened condition, however slight, beyond the neutral (physiological rest) position [26]. Changes in the direction of muscle pull as a result of an altered static skeletal alignment may affect the amount of muscle tension required to maintain a static position, thus possibly explaining chronic musculoskeletal weakness and pain experienced by women with breast hypertrophy.

Limitations and Future Research

One major limitation of this study is the hand position in which subjects were required to maintain throughout the data collection session. During times of data capture, subjects were required to place their hands on their hips throughout the duration of part or in some cases the whole task. While this is not necessarily a natural, relaxed position, it was necessary in order to prevent signal blockage or accidental contact to the sEMG electrode on the serratus anterior. Therefore, it is possible that this position altered the mechanics by which each task of daily living was performed, and may have caused a slight deviation in the subject's "normal" posture during static trials. However, since this hand position was uniform across all subjects for all trials, it is unlikely that it had a significant effect on the results of this study.

Another limitation associated with this study is the large standard deviation in posture data between subjects. The explanation for this error can be traced to issues in the performance of the tasks of daily living. Subjects were given the same basic instructions about how to perform each task. However in an effort to evaluate each subject's "natural" posture and mechanics used to perform each task, subjects were given instructions to perform each task as they "normally would." As a result there may have been a larger amount of variance in the performance of each task than was anticipated (i.e. bending at the waist to pick up a pencil will result in greater values of torso flexion than squatting down to pick up a pencil). Figures 18-21 provide a graphical representation of the differences between a normal control subject and a hypertrophy subject's average head flexion, pelvic tilt, scapular protraction, and torso flexion, respectively during the performance the pencil task.

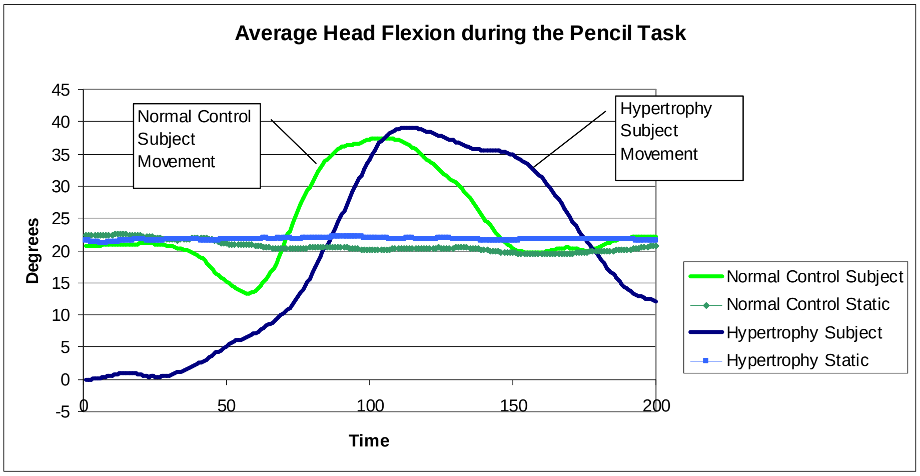

Figure 18. Comparison of Average Head Flexion during the Pencil Task

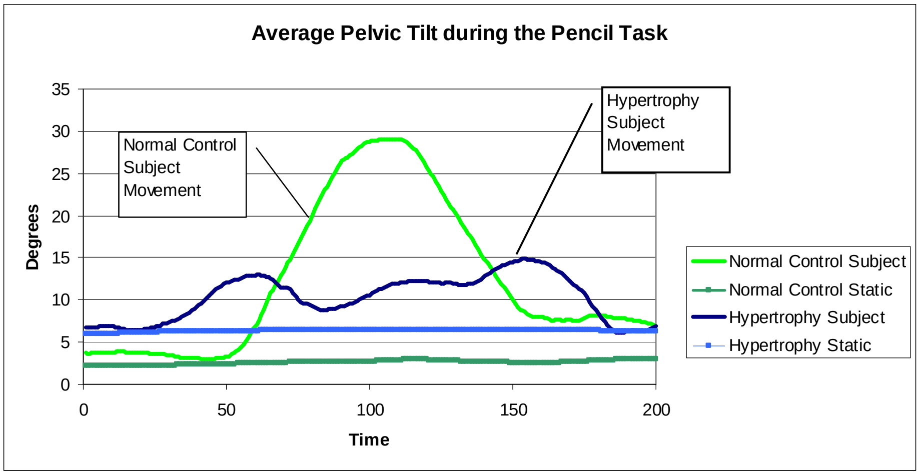

Figure 19. Comparison of Average Pelvic Tilt during the Pencil Task

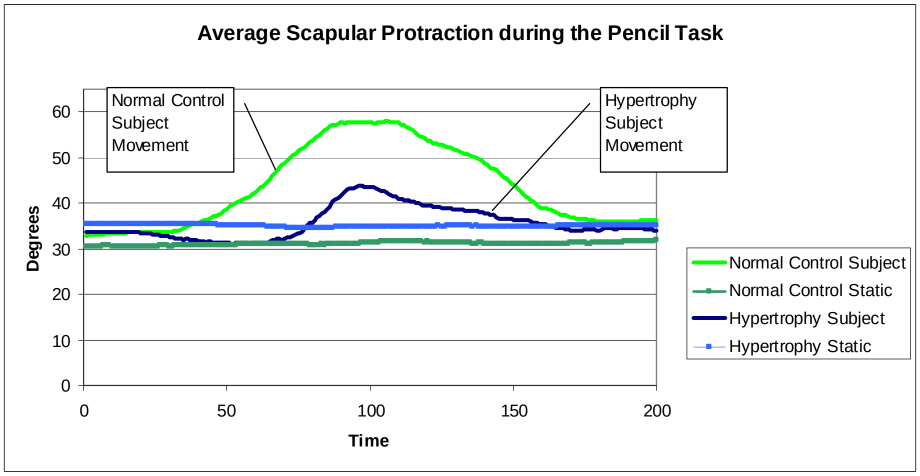

Figure 20. Comparison of Average Scapular Protraction during the Pencil Task

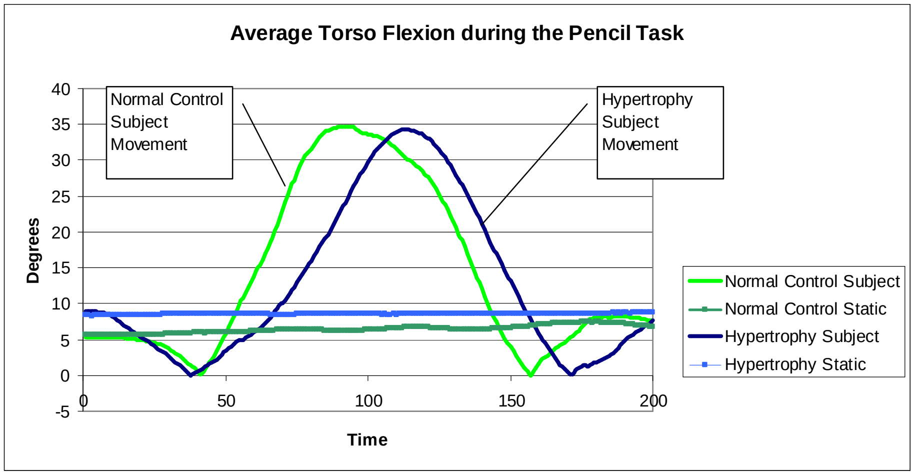

Figure 21. Comparison of Average Torso Flexion during the Pencil Task

This difference in movement between subjects may cause a change in the normalized values for movement during tasks of daily living (either an increase or decrease in value), possibly creating an outlier. While every effort was made to remove the most extreme outliers in the data set, some mild outliers may have remained and been included in the final analysis. Therefore, the variance in the performance of the tasks of daily living needs to be lowered so that the normalized data results are more consistent between subjects and the possibility of outliers is reduced.

Another limitation of this study is large standard deviations in the muscle activation data. This error may be traced back to the performance of MVC's since the resulting EMG signal is used to normalize all other tasks. The issues lie within the subjects and whether or not they fully exerted themselves during the MVC. If a subject did not fully exert herself during the MVC but did during one of the tasks, a value for normalized muscle activation (%MVC) greater than 100% could result. Therefore variance in the performance of the MVC needs to be lowered so that the normalized data results are more consistent between subjects.

Finally, of greatest limitation in this study is the power of each statistical test. Statistically it is ideal for each dependent variable's t-test to have a power of at least 0.80; meaning β (probability of making a type II error) has a value of 0.20. However, because the sample population in this study is so small and because the standard deviations for each task are so high, the resulting power for each test is low. As a result, some of the significant differences that were reported may not in fact be truly statistically significant because the power is too low. It can be postulated that a larger sample size is needed to detect a statistical significant difference in the dependent variables analyzed in this study since the differences between groups were so small. Based on data from this study, each group should have a population of at least 20 subjects in order to achieve the desirable power and to see true statistical differences between the two groups.

In terms of the design of this study, it is important to remember that all subjects were women who have never undergone nor have even been approved for breast augmentation surgery. It was important to study women who were not actively seeking breast reduction surgery in order to investigate trends in the musculoskeletal data for the "normal" population. Future research should examine women who have been approved for breast reduction surgery, and investigate differences in musculoskeletal biomechanics pre and postoperatively. Information from future research could provide strong scientific evidence of the medical necessity of reduction mammaplasty, thus changing criteria insurance companies use to determine eligibility for coverage.

Conclusions

Results of this study provide scientific information regarding the effects of breast hypertrophy on the musculoskeletal system. Of greatest interest, are the slight differences in both upper body posture and muscle activation seen in women with larger breast sizes under static conditions. Under static conditions, women with larger breasts exhibited increased head flexion, pelvic tilt, and torso flexion. Women with larger breasts also exhibited higher values of muscle activation in the midcervical neck muscles, upper trapezius, lower trapezius, serratus anterior, and erector spinae during static conditions, indicating an increase in muscle force required to maintain an upright position. While none of the postural alterations seen in women with large breasts were statistically significantly different from those seen in women with smaller breasts, the data presented shows a clinical trend towards altered musculoskeletal alignment due to the size and weight of larger breasts. Therefore, results of this study provide scientific evidence of the physical burdens placed on the musculoskeletal system in the case of breast hypertrophy, and should be considered when determining the medical necessity of reduction mammaplasty.

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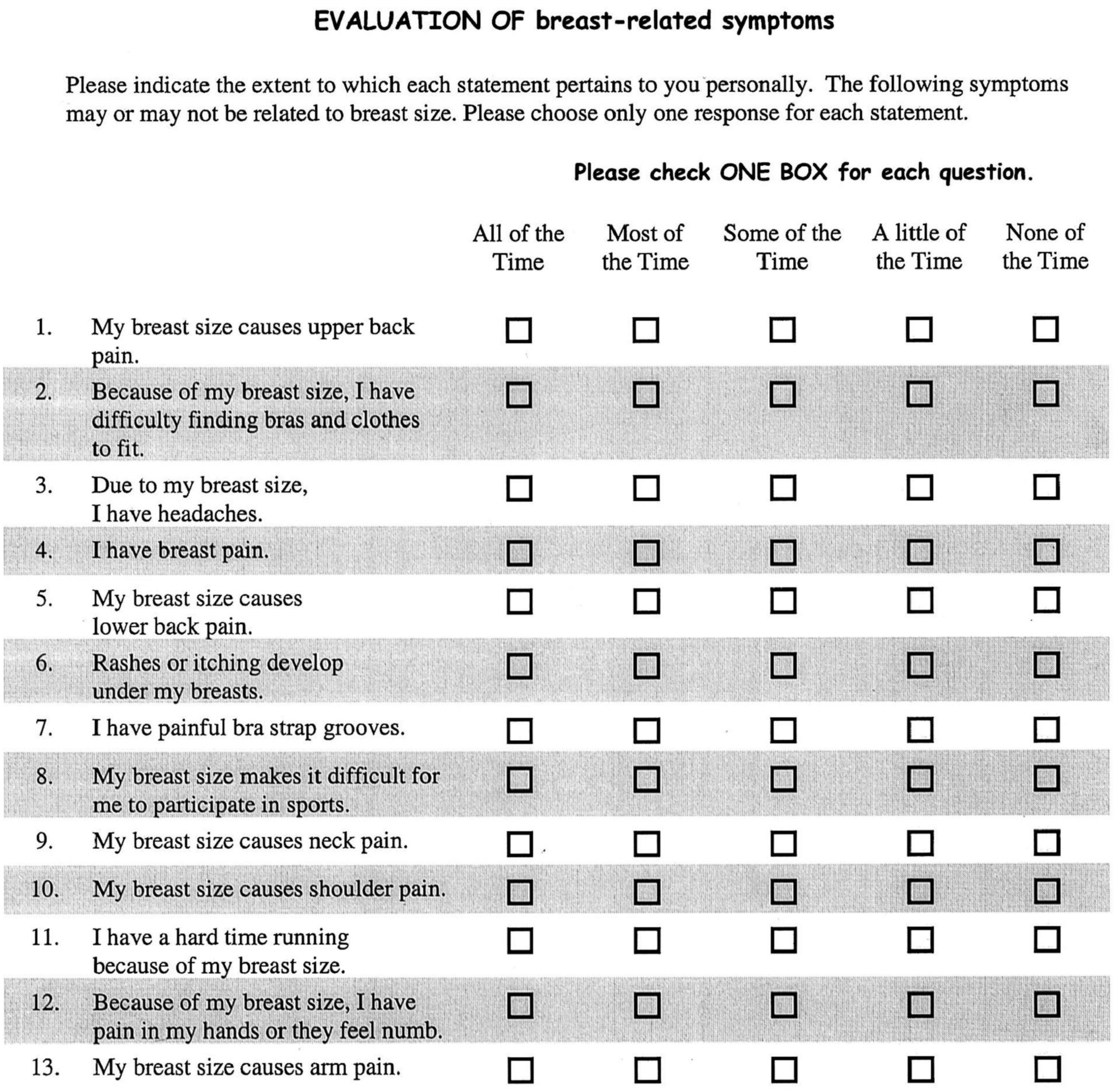
APPENDIX A

Breast Related Symptoms Questionnaire

Copy of the questionnaire each subject completed prior to data collection [21].



EVALUATION OF breast-related symptoms

Please indicate the extent to which each statement pertains to you personally. The following symptoms may or may not be related to breast size. Please choose only one response for each statement.

Please check ONE BOX for each question.

		All of the Time	Most of the Time	Some of the Time	A little of the Time	None of the Time
1.	My breast size causes upper back pain.	☐	☐	☐	☐	☐
2.	Because of my breast size, I have difficulty finding bras and clothes to fit.	☐	☐	☐	☐	☐
3.	Due to my breast size, I have headaches.	☐	☐	☐	☐	☐
4.	I have breast pain.	☐	☐	☐	☐	☐
5.	My breast size causes lower back pain.	☐	☐	☐	☐	☐
6.	Rashes or itching develop under my breasts.	☐	☐	☐	☐	☐
7.	I have painful bra strap grooves.	☐	☐	☐	☐	☐
8.	My breast size makes it difficult for me to participate in sports.	☐	☐	☐	☐	☐
9.	My breast size causes neck pain.	☐	☐	☐	☐	☐
10.	My breast size causes shoulder pain.	☐	☐	☐	☐	☐
11.	I have a hard time running because of my breast size.	☐	☐	☐	☐	☐
12.	Because of my breast size, I have pain in my hands or they feel numb.	☐	☐	☐	☐	☐
13.	My breast size causes arm pain.	☐	☐	☐	☐	☐

APPENDIX B

Pictures of Surface Electrode Placement

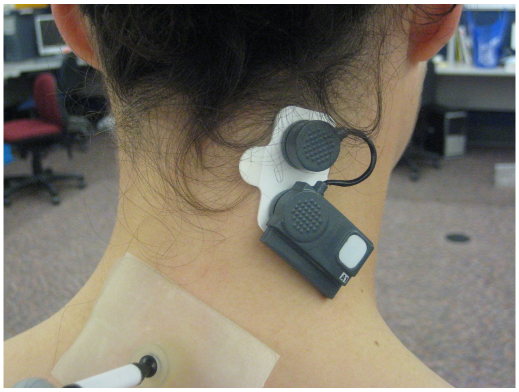


Figure B 1. Midcervical (C-4) Paraspinal Electrode Placement

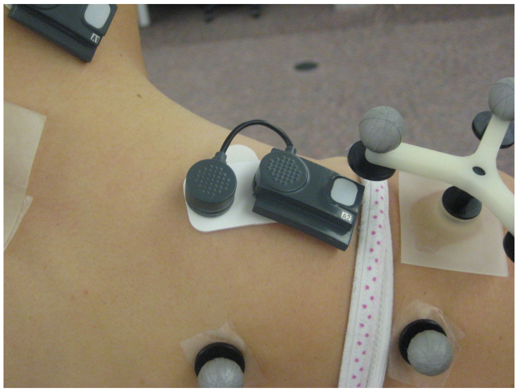


Figure B 2. Upper Trapezius Surface Electrode Placement

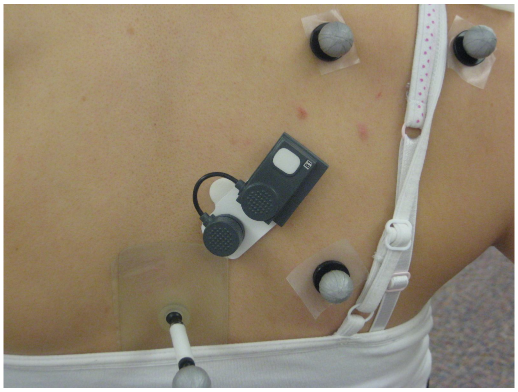


Figure B 3. Lower Trapezius Surface Electrode Placement

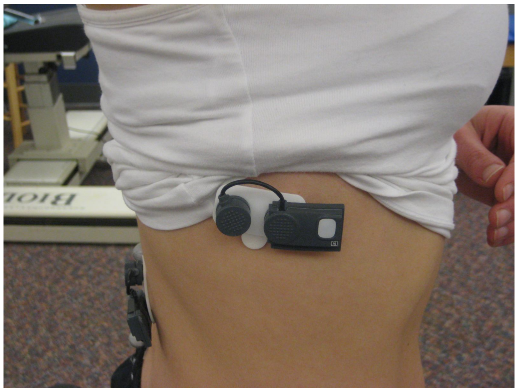


Figure B 4. Serratus Anterior Surface Electrode Placement

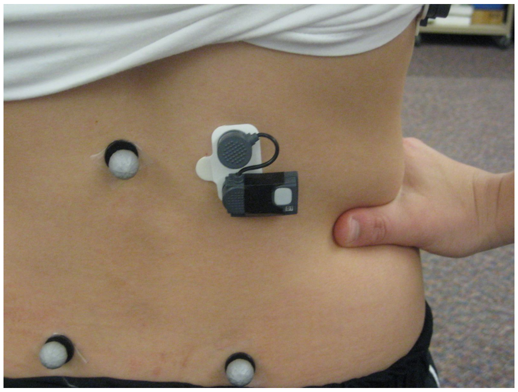


Figure B 5. Erector Spinae Surface Electrode Placement

APPENDIX C

Pictures of Complete Subject Setup

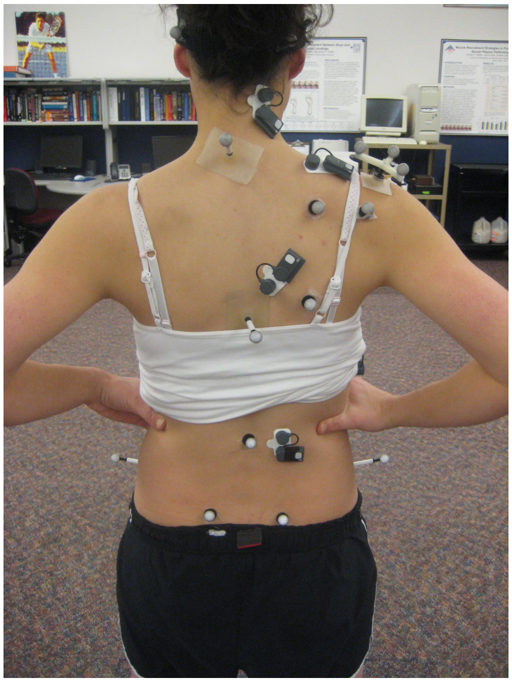


Figure C 1. Complete Subject Setup (Posterior View)

Figure C 2. Complete Subject Setup (Side View)