OBESITY AND ROTATOR CUFF TENDONITIS

A Thesis

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By

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ABSTRACT

There has been a rapid escalation in the percentage of obese population in the United States over the past 20 years. Obesity is known to cause some serious heath concerns like cardio-vascular disorders and cancer. A high body mass index has also found to be significantly correlated with increased incidence of shoulder pain and reduce range of motion at the shoulder. Rotator Cuff Tendonitis (RCT) is one of the most common ailments of the shoulder joint. The objective of the present study is to determine the correlation between Obesity and Rotator Cuff Tendonitis. The study consisted of 2 parts 1) Ex post facto analysis of 2004 data from the Medical Expenditure Panel Survey (MEPS) database to examine the relationship between Adult BMI and RCT and 2) Comparison of scapular kinematics between obese individuals and a non-obese control group. Out the total RCT (n=910) cases reported in the MEPS database for the year 2004 65% of the cases were found in the people with BMI above 25 (n=593). Using the Chi–square test the correlation between BMI and RCT was found to be statistically significant. Data for orientation of the scapula and humerus was collected using an electromagnetic motion capture system during three separate activities: raising and lowering their arm without a weight; raising and lowering the arm with a three pound dumbbell; and reaching behind their neck. The results from the separate 2 way ANOVA showed significant differences between groups for UR of scapula for both raising and lowering
phases in all 3 activities. Between group differences were significant for scapula tipping for raising and lowering the arm without any weight and reaching behind the back. These findings suggest that an overweight/obese individual is more likely to suffer from RCT. Therefore, the prevention and treatment protocols for rotator cuff tendonitis in overweight/obese population should include an adequate weight loss program. Ergonomic modifications aimed at decreasing muscular stresses across the shoulder should also be incorporated for overweight individuals to prevent / treat RCT.
DEDICATION

To Ma, Papa and Prateek.

For everything and more, thank you.
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CHAPTER 1
INTRODUCTION

Background of the problem

1.1 Obesity

Obesity has been defined in the medical dictionary as “the state of being well above one’s ideal weight”. A person weighing 20% over their ideal weight is considered to be obese. The World Health Organization (WHO) more precisely defines obesity as a Body Mass Index (BMI) of 30 or above. The BMI helps relate body weight to height and is calculated by dividing a person’s weight in kilograms (kg) by their height in meters (m) squared.

There has been a rapid escalation in the percentage of obese population in the United States over the past 20 years. Obesity prevalence has doubled between 1980 and 2002 in adults aged 20 years or older. An increase from 30.5% to 32.2% among adults above the age of 20 years has been noted from 1999-2000 to 2003-2004. The rate of increase in clinically severe obesity (BMI>40) has been faster than the rate of increase of moderate obesity (BMI; 30-40) among adults in the United States between 2000 and 2005.

Obesity creates some serious health concerns. Diseases affecting the heart and blood vessels leading to compromised vascular conditions have been identified as
common morbid ailments among the obese\textsuperscript{8}. The prevalence of medical conditions such as diabetes, heart disease, hypertension and asthma has been noted to increase with increased BMI levels\textsuperscript{9}. The musculoskeletal system has also been found to be significantly affected in the obese \textsuperscript{8,10}. Obesity has been associated with decreased aerobic capacity\textsuperscript{11} and low muscular endurance\textsuperscript{12}. This predisposes individuals with high body mass to musculoskeletal injuries. Adverse effects in an obese individual’s muscle strength could be a result of increased body mass and decreased percentage of fat free mass\textsuperscript{13}. Conditions like osteoarthritis and low back pain have also been found to be significantly associated with obesity\textsuperscript{14}.

Although some studies suggest an association between musculotendinous conditions of the upper extremity and obesity\textsuperscript{15}, the majority of studies have primarily focused on the effect of increased body mass on the weight bearing bones and joints of the body, i.e. lower extremity and trunk. Increased weight of the upper extremity can create undue stresses on the joints and muscles of the arm leading to pain and injury. The shoulder joint is one of the primary joints of the upper extremity which may be affected as a result of increased joint loading. In order to determine the impact of obesity on upper extremity joints such as the shoulder, it is important to understand the anatomy of the shoulder complex.

1.2 The Shoulder Complex

The skeletal make-up of the shoulder complex consists of the scapula, humerus, and clavicle, a series of bones interacting to connect the arm to the trunk\textsuperscript{16}. The scapula sits between the 2\textsuperscript{nd} and the 7\textsuperscript{th} ribs posteriorly, and the clavicle meets the sternum.
anteriorly to connect the shoulder to the thorax. The clavicle also articulates with the acromion of the scapula to form the acromioclavicular joint (AC) at one end, and with the sternum to form the sternoclavicular joint (SC) at the other end. The scapulothoracic joint (ST) is a planar articulation between the scapula and the ribs. The humerus joins the scapula at the glenohumeral (GH) joint. The movement of the shoulder complex across these joints are controlled by 17 muscles\textsuperscript{16}, including the 4 rotator cuff muscles.

Fig 1.1-The Shoulder Region

1.3 The Rotator Cuff

The Rotator Cuff is made up of 4 muscles whose tendons combine at the humeral head to form a thick “cuff” surrounding the GH joint\textsuperscript{16, 17}. The muscles of the rotator cuff are the supraspinatus (SS), infraspinatus (IF), teres minor (TM) and subscapularis (SU).
Each of these muscles originates from the scapula and inserts into the humerus. These muscles play a significant role in providing stability to the GH joint\textsuperscript{17}. Their activity during arm elevation results in generation of compressive forces at the GH joint which approximates the head of the humerus into the glenoid fossa of the scapula. These muscles also help limit humeral head translation when the arm is subjected to external loading\textsuperscript{18,19}.

1.4 Scapular Kinematics

Normal function of the shoulder complex is possible with synchronous movement among the 4 joints through activation of the many muscles of the shoulder complex. Movement of the arm is clinically described as flexion (raising the arm in front), abduction (raising arm to the side), extension (taking the arm back) and adduction (bringing the arm towards the midline of the body). Scapular plane abduction describes raising the arm in a plane approximately 40 degrees anterior to the abduction plane. Flexion, abduction, and scapular plane elevation are common movements used to perform many important activities in daily life. In addition to GH movement, full range of these shoulder motions requires appropriate movement of scapula on the thorax and rotation of clavicle. Of particular importance, the ST joint motion allows the scapula to provide a stable base of support for the GH movements\textsuperscript{16}.

During abduction, the initial 15-20\degree of motion occurs only at the GH joint\textsuperscript{16}. As the arm elevates further, movement at the ST joint also occurs and the scapula progressively rotates upwardly, externally and tilts posteriorly\textsuperscript{20,21}. [Figure 1.2] Because the scapula is connected to the clavicle at the AC joint, elevation of the arm also results in
retraction, elevation, and posterior rotation of the clavicle\textsuperscript{22}. These movements at different joints are made possible by the activity of the different muscles acting across these joints. The rotator cuff muscles, through their origin at the scapula and their stabilizing effect on the GH joint, play an important role in maintaining the normal scapular kinematics\textsuperscript{17, 18, 19}. 

Fig 1.2 Scapular motion

(Source: Riek et al Spinal Cord (2007), 1–9)
1.5 Rotator Cuff Tendonitis

Inflammation of one or more of the tendons of the rotator cuff muscles is known as rotator cuff tendonitis (RCT). Any form of injury to the rotator cuff results in an initial inflammatory response. Mechanical impingement of the rotator cuff tendons in the space between the acromion process and the humerus (the subacromial space), repetitive trauma to the tendons with everyday movement of the shoulder, or degeneration of the tendons with age are some of the causes associated with RCT. This inflammation may progress to partial or total rotator cuff tears if left untreated. The precise etiology of rotator cuff tendonitis can be multifactorial and is therefore often difficult to determine.

Anatomical causes like the shape of the acromion process of the scapula affects the amount of friction between the rotator cuff tendons and the acromion process. Increased friction between the tendons and the acromion process has been associated with higher incidence of rotator cuff tears. RCT has also been associated with instability of the GH joint. Excessive superior translation of the humerus with arm elevation in an unstable GH joint causes narrowing of the subacromial space and result in rotator cuff impingement. Repetitive overhead activities may also be a cause of GH instability.

Continuous microtrauma due to repetitive overhead stress causes attenuation of the glenohumeral ligaments at the shoulder joint. This compromised static stability results in a compensatory increase in rotator cuff activity, subjecting them to early fatigue. The result is excessive anterior translation of the humeral head and mechanical impingement of the supraspinatus tendon. Age–related degenerative changes are also known to occur in the rotator cuff tendons and microtrauma to these already weakened tendons causes inflammation and progressive tearing of the rotator cuff.
Decreased blood supply to the rotator cuff resulting in decreased oxygen delivery and nutrition supply may also make them susceptible to injuries. Codman identified a critical zone of decreased blood supply near the insertion of the supraspinatus tendon at the humerus and the majority of the degenerative changes in the cuff have been reported to occur at this site\textsuperscript{29}.

Poor posture may create muscle length imbalances and lead to altered forces at the shoulder joints. As multiple muscles connect the spine to the scapula, these altered forces may result in abnormal scapular motion in people with forward head posture and kyphotic thoracic postures\textsuperscript{30}. These altered scapular motions have been demonstrated in individuals with rotator cuff impingement\textsuperscript{30}.

**Scapular kinematics in RCT**

Altered scapular kinematics have been reported patients with rotator cuff injuries \textsuperscript{21,31-34}. Abnormal position or orientation of the scapula during arm elevation negatively affects the subacromial space and results in impingement of rotator cuff tendons. Lukasiewicz et al\textsuperscript{31} found lack of posterior tilting and excessive superior translation of the scapula during shoulder abduction in patients with shoulder impingement. Normally, posterior tilting of the scapula prevents excessive compression of the tendons in the subacromial space with arm abduction\textsuperscript{16}. Loss of posterior tilting results in a relatively anteriorly tilted scapula which narrows the subacromial space and may contribute to impingement and inflammation of the rotator cuff tendons\textsuperscript{31}. Weakness or early fatigue of the rotator cuff muscles because of impingement or inflammation results in excessive superior translation of the scapula\textsuperscript{31}. Altered upward rotation\textsuperscript{22,32} of the scapula or
increased internal rotation of the scapula\textsuperscript{33, 34} during arm elevation may also result in impingement of the rotator cuff tendons in the subacromial space.

**Obesity and RCT**

Obesity has been documented as a possible risk factor for upper extremity musculoskeletal pain and disability\textsuperscript{35-37} for various reasons. Increased prevalence of vascular conditions such as atherosclerosis, hypertension and diabetes has been found in people with a high body mass index\textsuperscript{7-9}. Presence of these conditions decreases the blood supply to various parts of the body. Decreased blood supply to the rotator cuff tendons, particularly the supraspinatus, increases the risk of developing RCT.

The poor postural habits common in people with increased body mass may also contribute to the development of RCT. The obese population has been documented to adopt greater flexion positions at the thoracic and pelvic levels while performing standing tasks\textsuperscript{38}. Exaggerated flexion postures have been associated with abnormal scapular kinematics\textsuperscript{39} lowering the threshold for developing rotator cuff tendonitis\textsuperscript{30}.

Weakness and early fatigue of muscles are common complaints in the obese. These complaints are associated with lack of exercise and sedentary lifestyle in the obese\textsuperscript{4, 8, 10}. The increased mass of the upper extremity may create greater stresses on the already weakened and fatigued rotator cuff muscles and contribute to abnormal scapular kinematics. Microtrauma to these compromised muscles while performing daily activity may then result in RCT\textsuperscript{27-28}.
Significance of the problem

The increase in obesity in the United States over recent years emphasizes the need to study its effects on different aspects of human health. RCT has been reported as one of the common shoulder impairments among the general population and obesity may be an important factor for the onset or propagation of RCT either directly because of an increase in upper extremity mass or indirectly because of associated vascular, muscular, or kinematic alterations. A study to both determine the existence of an association between obesity and RCT and to examine a potential cause will help redesign the prevention and treatment protocols for rotator cuff tendonitis in this population which could include an adequate weight loss program. Ergonomic modifications aimed at decreasing muscular stresses across the shoulder could be incorporated for overweight individuals to prevent and treat RCT. Specific strengthening protocols may also be indicated.

Objectives

The purpose of the study is to

1. Analyze data from a large-scale database to examine the relationship between Adult BMI and RCT.
2. Compare three-dimensional scapular kinematics in a group of obese individuals to a non-obese control group.
**Hypotheses:**

1. Adult BMI is positively correlated with the number of RCT cases reported in the MEPS database.

2. Scapular kinematics in a group of obese individuals will differ from the kinematics in a group of lean individuals.

3. Scapular kinematics in a group of obese individuals will be similar to the kinematics seen in groups of individuals with RCT.

**Glossary:** Obesity, Body Mass Index, rotator cuff tendonitis, scapular kinematics.
2.1 Obesity: Trends and Prevalence

Flegal et al.\(^3\) examined the trends and prevalence of overweight and obesity in the United States in 1999 and 2000. They calculated BMI from a survey of 4115 adult men and women from the National Health and Nutrition Examination Survey (NHANES) database, which collects data from a nationally representative sample of the United States population. The authors’ used age-adjusted prevalence of overweight (BMI \(>25\)), obesity (BMI \(>30\)) and extreme obesity (BMI \(>40\)) as their main outcome measures. After comparing their findings with earlier surveys conducted by NHANES, they reported an increase of age-adjusted prevalence of obesity from 22.9% in 1988-1994 to 30.5% in 1999-2000. The prevalence of overweight had also increased to 64.5% from 55.9% during this period. A significant increase in prevalence for extreme obesity from 2.9% to 4.7% was also reported in the population. This increase was significant across all age groups for both men and women.

The same authors’ performed a similar study in 2003-2004. Ogeden et al.\(^5\) conducted an analysis of the NHANES data from 4431 adults aged 20 years or older. 32.2% of adults were found to have a BMI \(>30\). The prevalence of body mass index \(>40\) was found to vary between men (2.8%) and women (6.9%) during this period.
Significant differences in obesity prevalence varied between age groups with a maximum of 36% of the adults aged between 40-59 years. Among the other age groups, 28.5% of adults aged 20 to 39 years, and 31.0% of those aged 60 years or older were found to be obese. In comparing these findings to the NHANES data collected for the years of 1999-2000 and 2001-2002, a significant increase in the prevalence of obesity from 27.5% in 1999-2000 to 31.1% in 2003-2004 was noted among men. However, the analysis did not reveal significant differences between in obesity prevalence among women during these time periods.

Sturm performed an analysis on the data from The Behavioral Risk Factor Surveillance System (BRFSS), a random-digit telephone survey of the household population of the USA, to study the increases in morbid obesity from 1986 to 2005. Self reported height and weight was used to calculate BMI. He reported a 24% increase in the prevalence of obesity (BMI over 30) from 2000 to 2005. Faster rates of increase in the prevalence of BMI were noted for those groups with higher calculated BMI during this period. In comparison to the population with BMI over 30, the prevalence of BMI over 40 was found to have doubled to 50% and that of BMI over 50 to have tripled to 75% during the this time.

It is important to note that unlike the studies conducted using the NHANES database where the data is collected objectively, the Sturm study might underestimate the actual trends because the data collected by the BRFSS is self reported and the tendency to under or over report one’s weight has been well documented. Even then, it may not be fair to undermine the importance of the Sturm study because under-reporting of weight has been found to increase with increased weight. This implies that the increased
prevalence reported by Sturm may be underestimated and the increase in obesity rates over the years may actually be higher.

2.2 Obesity and Health Risks

According to Kopelman\textsuperscript{8}, decreased physical activity, genetic susceptibility, and increased availability of quality food items are a few factors that lead to obesity. He found abdominal obesity to be common in people with high body mass index and to be associated with a number of morbid diseases such as diabetes, hypertension, coronary heart disease, gallbladder disease, and certain types of cancer\textsuperscript{8}.

Colditz et al\textsuperscript{44} reported an association between diabetes and increasing BMI in their Nurses’ Health Study. The study reported results after 14 years of prospective follow up of more than 114,000 registered nurses. The age-adjusted risk of developing type 2 diabetes was found to rise steadily with increasing BMI relative to lean women (BMI < 22 kg/m\textsuperscript{2}). In comparison to lean women, the obese women (BMI > 35kg/m\textsuperscript{2}) were found to be 93 times more prone for developing diabetes.

Obesity has also been associated with increased mortality due to cancer. In another Nurses’ Health Study by Manson et al\textsuperscript{45}, cancer mortality for obese women (BMI > 32 kg/m\textsuperscript{2}) was twice the mortality rate for lean women (BMI<19 kg/m\textsuperscript{2})

Wilson et al\textsuperscript{46} examined the relationship between BMI, cardiovascular disease and vascular diseases in a population sample of 5209 participants between the ages of 35-75 years from the Framingham Heart study. The participants were examined every 2 years after the initial examination for 44 years for any cardiovascular disease event and changes in risk factor status. Using the cross sectional pooling method to reassess the
population every 2 yrs they reported the age-adjusted relative risks of hypertension and cardiovascular diseases to be highly associated with overweight and obesity.

Obesity has also been associated with several musculoskeletal conditions. Tsuritani et al\textsuperscript{47} studied the impact of obesity on musculoskeletal pain and difficulty of daily movement in 709 Japanese women between the ages of 40-69 years. The authors found higher BMI to be associated with increased prevalence of frequent leg pain and disability. Other studies have documented obesity as a primary risk factor for lower extremity musculoskeletal conditions like osteoarthritis\textsuperscript{48} and heel pain\textsuperscript{49}.

2.3 Obesity and Posture

Because the constant influence of increased mass may overburden the musculoskeletal system, obesity may cause compensatory postural adaptations. Gillear and Smith\textsuperscript{38} studied the effect of obesity on posture and hip joint moments during a standing task and trunk forward flexion motion. They found the obese group to have decreased thoracic segment angular displacement and thoracolumbar spine range of motion during seated forward flexion. They also observed that the obese group stood further away from the work bench while performing standing tasks as compared to the control group, resulting in greater flexion postures at the thoracic and pelvic segments. BMI was found to have a significant correlation with the posture of the thoracic segment and hip-to-bench distance, and the posture of the thoracolumbar spine, indicating that as BMI increased, the posture was more flexed and the hip-to bench distance increased while performing a standing functional task. However, postural changes observed while performing a functional activity are short-term and may not cause permanent musculoskeletal changes. The authors do not report any postural differences in normal
stance between the obese and non-obese group. An abnormal posture at rest may suggest muscular imbalance which may lead to altered biomechanics and over time result in pain and injury to the muscles.

2.4 Prevalence of Rotator Cuff Tendonitis (RCT) in the general population

A 2-stage cross sectional survey of 9,696 randomly selected adults involving screening and questionnaire and a standardized physical examination of symptomatic subjects was conducted by Walker-Bone et al. to explore the prevalence of RCT. The response rate was 62% with replies from 6,038 of the contacted individuals. Fifty-two percent (3,152) of the responding subjects where found to have symptoms of upper extremity disorders, of which 62% (1,960) were examined and interviewed. Based on the examination, 4.5% of the 777 men and 6.1% of the 1,183 women were diagnosed positive for RCT. Thus, RCT is one of the primary reasons of shoulder pain and seems to affect more women than men. Identifying factors that lead to development of RCT may, therefore, help reduce the incidence of rotator cuff injury. It will also make way for better treatment protocols to enable faster and long term recovery.

2.5 Etiology of RCT

Different theories have been cited for the initiation and propagation of tendon disorders such as RCT. According to the mechanical theory by Reese et al., repeated loading of the tendon even within the normal physiological stress range of the tendon leads to fatigue and eventually tears within the tendon. The increased incidence of tendinopathy with age and in the active population as documented by Miranda et al. and Makela et al. is consistent with this theory. In a cadaver study by Reilly et al.,
10 fresh cadavers were tested on a purpose built rig, static loading of more than 100N and GH abduction of 120 degrees were found to cause differential loading of the SS tendon on the bursal and the joint sides. Static loading resulted in higher strains on the bursal side whereas GH abduction was associated with greater strains at the joint side. They concluded that this differential strain between the bursal and the joint side generated shearing forces between the layers of the SS tendon that could result in propagation of intratendinous microdamage. A combination of increased joint loading and repetitive activity may therefore accelerate the tendinous microdamage, progressing to an RCT. Weak muscles or decreased muscular endurance in addition to the above factors would likely accelerate this process.

The vascular theory proposes that a compromised blood supply to the tendon is the reason for most symptomatic tendons. Rees et al have described tendons as being “metabolically active tissues” which require continuous vascular supply. Codman identified a “critical zone” with decreased blood supply near the insertion of the SS tendon where most injuries were found to occur. More recently Ling et al studied the vascular supply of the rotator cuff in 22 adult shoulders by way of mixture infusion and vascular cast, in combination with Scanning Electronic Microscopy of the SS. They confirmed the macroscopic appearance of an avascular zone or critical zone on the surface of SS at a mean distance of 7.8mm from the external edge of the osteotendinous attachment. They also reported that the size of this critical zone increases with age. This theory is consistent with the increased incidence of SS lesions among older patients with conditions affecting vasculature such as diabetes mellitus. Therefore, the presence
of vascular conditions such as atherosclerosis and hypertension, which affect the blood supply to the tendons, may increase the risk for developing RCT.

2.6 Scapular Kinematics in RCT

In a comparative study of scapular orientation between 17 subjects with impingement and 20 subjects without impingement by Lukaseiwicz et al\textsuperscript{31}, a significant decrease in posterior tilting of scapula was reported with scapular plane humeral abduction in the subjects with impingement. The scapular orientation was studied using a 3-D electromechanical digitizer with data collected at 3 static positions of arm elevation. The subject was asked to hold their arm at maximum abduction, 90 degree abduction in the scapular plane and by the side. The authors did not find significant differences for scapular internal rotation or upward rotation between the two groups in their study.

GH and ST kinematics were analyzed by Ludewig and Cook\textsuperscript{33} in 52 subjects, 26 with symptoms of shoulder impingement and 26 control subjects. All subjects were recruited from a population of construction workers who performed daily overhead activities. The authors recorded 3D orientation of the trunk, scapula and humerus using electromagnetic sensors. Data was collected during dynamic humeral elevation in the scapular plane under 3 hand–held load conditions of no load, 2.3 kg load and 4.6 kg load. An analysis of variance model for assessment of group and load effects revealed significant alterations in the scapular kinematics of subjects with impingement. The general pattern of scapula movement with arm abduction in the group without impingement was noted as upward rotation accompanied by decreased anterior tipping position of the scapula and lateral rotation of the humerus. However, decreased upward
rotation of the scapula and increased anterior tipping of the scapula were reported in subjects with rotator cuff impingement.

Similar findings were reported by Borstad and Ludewig\textsuperscript{34} who compared scapula orientation between dynamic elevation and lowering phases of arm abduction in the scapular plane in the same 52 subjects with and without impingement. A 3D analysis of scapular orientation in relation to the thorax performed at 40°, 60°, 80°, 100° and 120° revealed statistically significant alterations in scapular orientation in the symptomatic subjects during the eccentric arm lowering phase. Anterior tipping of the scapula at higher arm elevation angles was greater in symptomatic subjects as compared to the control group. Upward rotation of the scapula was also found to be decreased in the group with impingement. Even though significantly increased internal rotation of scapula at 100° was common in subjects with and without impingement during the eccentric phase, subjects in the impingement group were also found to have increased internal rotation at 120°.

It is important to note that most of the studies to determine altered scapular kinematics in subjects with impingement have been carried out in subjects with existing signs and symptoms of impingement. It remains unclear if the observed changes in kinematics are the result of impingement of rotator cuff tendons or the cause for initiation of rotator cuff tendinopathy.

2.7 Obesity and shoulder impairment

Obesity has been found to be significantly correlated with shoulder musculoskeletal conditions. In a prospective cohort study, Luime et al\textsuperscript{54} studied the incidence and recurrence of shoulder and neck complaints among 769 workers of nursing
homes and homes for the elderly. They took into consideration personal risk factors along with work-related physical and psychosocial factors. Using a multivariate model adjusted for age and gender, obesity was found to be significantly correlated to the incidence of shoulder complaints. Significant associations were also noted between chronic complaints at baseline and recurrence of shoulder and neck complaints. Complaints of shoulder and neck pain were not correlated with work-related risk factors.

Miranda et al. found obesity to increase the risk of incident shoulder pain in a longitudinal study. They sent out questionnaires on musculoskeletal pain and potential risk factors for 4 consecutive years (1992-95) to the workers in a large Finnish forestry company. The response rate to the questionnaire in 1995 has been reported to be 90%. They studied the predictors of 1 year incidence and persistence of shoulder pain using multivariate regression modeling and reported that 14% of the 2094 subjects who were initially free of shoulder pain reported of having mild or severe shoulder pain. BMI was found to positively correlate with risk of incidence of shoulder pain.

Obesity and diabetes mellitus were reported as two potentially treatable factors associated with reduced flexion range of the shoulder and the elbow by Escalante et al. They studied the association between shoulder and flexion range of motion with demographic and anthropometric characteristics in 695 community dwelling subjects aged 65-74 yrs. Their analysis also included presence of diabetes mellitus or self reported physician diagnosed arthritis. Examination using multivariate regression models revealed significant association between high body mass and reduced flexion ranges of the elbow but not the shoulder. Reduced elbow range of motion may result in higher stresses at the
shoulder while performing reaching activities in the obese population, thus predisposing them to shoulder impairments.

In another study by Makela et al.\textsuperscript{36} the prevalence and risk factors for shoulder impairments in Finns over the age of 30 yrs were studied. Out of 893 subjects with BMI between 30-35, 35.6% of subjects reported a recent episode of shoulder pain and another 12.2% were found to have shoulder impairment such as pain and limited mobility. One-hundred eighty-three subjects had a BMI \( \geq 35 \), of which 39.9% had recent shoulder pain and 12.6% suffered from shoulder impairments. The logistic regression modeling of the prevalence of any shoulder impairment did not reveal significant odd ratios in the above 2 groups, perhaps due to the small sample size. Also, the association between BMI and shoulder impairment may have been more evident if the authors had grouped together the subjects with BMI between 30-35 and BMI \( \geq 30 \).

Despite there being a number of studies which list obesity as a potential risk factor for shoulder pathology, there is little evidence for an association between high body mass and specific shoulder conditions like RCT. In attempt to investigate this association, Wendelboe et al.\textsuperscript{33} conducted a frequency matched case-control study where 311 patients between the ages of 53-77 yrs of age who had undergone any form of surgical shoulder repair served as subjects. The patients were age matched and frequency matched to 933 controls selected randomly from a cancer screening program in the same hospital. The authors found an association between increasing BMI and shoulder repair surgery using the International Classification of Diseases, ninth division procedural codes (ICD-9 PC) and BMI groups. Individuals with a BMI \( \geq 35 \) were found to have greater number of shoulder surgeries than individuals with lesser BMI’s.
These studies suggest that obesity may be associated with conditions resulting in shoulder pain. Wendelboe\textsuperscript{33} reported a correlation between obesity and RCT by studying the number of shoulder surgery cases. However, all RCT patients do not require surgical treatment and the results of this study might be underestimated.

The rise in number of obese individuals\textsuperscript{3, 5, 6} and the correlation between obesity and health problems\textsuperscript{7-10} has been well documented. Obesity has been found to be correlated with shoulder pain and shoulder surgeries\textsuperscript{15, 35}. However, these studies do not identify a specific shoulder condition or investigate the underlying cause for this correlation. An association between obesity and RCT may indicate that overweight individuals are more likely to suffer from RCT at a younger age than lean individuals. Studies which directly correlate the prevalence of RCT and obesity and examine the possible cause for this association will be useful in designing prevention and treatment protocols for pain and discomfort due to RCT.
CHAPTER 3

METHODS

Objective 1. Analyze data from a large-scale database to examine the relationship between Adult BMI and RCT.

3.1 Medical Expenditure Panel Survey Overview

To determine the correlation between obesity and RCT, the publicly available data files by MEPS from the year 2004 were analyzed. The MEPS conducts large scale surveys interviewing Americans all over the country to provide data for the frequency of use and cost of health services. It also collects data to determine scope of health insurance provided to the workers in the United States. The survey has been divided into two major components-1) Household Component (HC) and 2) Insurance Component(IC). The IC collects detailed data associated with insurance plans offered by different employers to their employees, whereas the HC collects information at the household level about the family’s/individual’s health status, demographics, health conditions, access to care etc. Personal data for an individual such as height, weight, BMI, type of disability, medical symptoms and diagnosed medical conditions are reported in the HC data files.
3.2 MEPS data collection and survey design

The household component of MEPS (MEPS-HC) interviews a sample of individuals and families from selected communities all over the United States. This sample is drawn from a nationally representative subsample of participants of one of the surveys conducted by National Center for Health Statistics. The database provides data for both adults and children. A key person in the household is identified and interviewed. Information regarding each individual of the household is collected during the interview. Data is collected about every single person in the household\textsuperscript{58}.

The survey follows an overlapping panel design according to which a new panel of subjects is chosen every year\textsuperscript{59}. Each panel is used to collect data for 2 calendar years. The two year data is collected through five rounds of interviews conducted over a period of 2 and half years. The two year data is collected through five rounds of interviews conducted over a period of 2 and one-half years. Each calendar year thus has data collected from 2 panels.

Data is collected via Computer Assisted Personal Interviewing (CAPI). The CAPI makes it possible to cover the large assortment of questions yet minimize the number of questions through skip patterns and questionnaire modules grouped into sections. The MEPS-HC data for each year has been divided into different files. The collected data is made available publicly at the MEPS website (www.meps.ahrq.gov) through downloadable data files. Different files can be linked together either by a common variable to carry out an analysis. 2004 is the recent most year for which complete data is available on the website.
3.3 Data Preparation

In every file each subject is represented by a Person ID (PID) variable, and each household by a Dwelling Unit ID (DUID) variable. Both these variables are combined to form another identifying variable – DUPERSID which is unique for each individual in all the 2004 data files. Full-year Consolidated Data files contain person-level data for the calendar year and were used to determine BMI of an individual. The International Statistical Classification of Diseases and Related Health Problems (ICD) designed by the World Health Organization (WHO) provides codes to classify various diseases. These codes are used in hospitals and clinics to document a physician’s diagnosis. The medical conditions file in the MEPS database also uses these ICD9 condition codes to report an individual’s diagnosed medical condition. Multiple medical conditions for the same individual are reported as multiple cases in the same data file. To extract the information needed for this study, the 2004 Full-year consolidated file was linked to the 2004 Medical conditions file with the common DUPERSID variable. BMI was recoded into categorical variables. Group 1 included individuals with BMI <22.9, Group 2 with BMI between 23 and 26.9, Group 3 included individuals with BMI \( \geq 27 \). The ICD9 codes 726, 727 or 840 were used to identify patients with RCT.

In all the data files, data for a person is missing if the question was skipped during the interview or if a question was unanswered by the person.

3.4 Data Analysis

A total of 32,737 persons were interviewed in the year 2004. Linking the files resulted in a total of 106,738 cases. The data were processed to eliminate missing values
for BMI and ICD9 codes. Only the cases with the required ICD9 codes -726, 727 or 840 were selected for further analysis. A Chi–Square test was used to determine if the BMI groups had differing frequencies of occurrence for RCT. Statistical significance was set at $p < 0.05$.

**Objective 2.** Compare three-dimensional scapular kinematics in a group of obese individuals to a non-obese control group.

### 3.5 Subject selection

Volunteers were sought by posting flyers in Atwell Hall, location of the School of Allied Medical Professions, and by personally inviting students in various graduate programs at The Ohio State University. Subjects were included if they were above the age of 18, without current shoulder pain or a history of shoulder surgery in the dominant shoulder.

### 3.6 Research design

A total number of 40 subjects were tested. To analyze the data, 2 groups were created: Group 1 = BMI <23 and Group 2 = BMI >27. Subjects with BMI ranging from 23-27 were excluded as it has been noted that the standard BMI cut off of 25 used for categorizing overweight subjects often results in muscular subjects being misclassified\(^6\).

For the kinematic analysis, three-dimensional orientation of the scapula and humerus relative to the trunk was captured. Other variables measured included individual’s 1) height 2) weight 3) arm skin fold thickness 4) thoracic kyphosis during
normal stance. Height and weight were used to calculate the subject’s BMI. Skin fold measurements were used to determine if the subcutaneous tissue mass of the arms of the obese group was greater than that of the lean group. To determine if differences in scapular kinematics are related to postural differences between the 2 groups, thoracic kyphosis during normal stance was measured.

3.7 Data Collection

After signing an institutionally approved informed consent, subject height and weight were measured on a mechanical scale with a built-in ruler. The skin folds were measured to the nearest millimeter for triceps and biceps were collected with a Lange skin fold Caliper (Cambridge Scientific Industries Inc. Cambridge, Maryland). Vertical skin folds halfway between the shoulder and the elbow, anteriorly between greater tuberosity and the center of cubital fossa for biceps and posteriorly between the olecranon and the acromial process of the scapula for triceps were measured. Three readings were recorded for each site and the average was used for the final analysis.

The Index of Kyphosis (IK), an estimate of posture, was measured with a flexible ruler. The ruler was placed on an individual’s back with one end at the C7 vertebrae and molded to the contour of the entire thoracic spine. The curve was then traced on a graph paper and the IK calculated using the Milne and Williamson protocol. In their formula thoracic width (TW) was divided by the thoracic length (TL) and the result multiplied by 100 (Figure 3.1).
Data for orientation of the scapula and humerus relative to the trunk were collected using an electromagnetic motion capture system. Only the dominant side shoulder was tested. Three sensors for motion analysis were taped to the subjects’ skin over the sternum, acromion, and distal humerus with hypoallergenic tape. Data were collected during three separate activities: raising and lowering their arm in the scapular plane without a weight; raising and lowering the arm in the scapular plane with a three pound dumbbell; and reaching behind their neck. The subjects were asked to perform 5 repetitions for each task. Movements in the scapular plane were performed with the thumb pointing up, whereas the subjects self selected the motion as they reached behind their neck. For all three tasks subjects self selected the speed of the motion.

At the time of analysis, 25 subjects had been measured (Group 1 n = 12, Group 2 n= 13). For the kinematic analysis, the dependent variables were i) Scapular Upward...
Rotation (UR) ii) Scapular Internal Rotation (IR) and iii) Scapular Tipping (Tipping). BMI group (low, high) and arm elevation angle relative to the trunk (60°, 90°, and 120°) were the independent variables. Patients with RCT usually complain of pain between 60°-120° of humeral abduction, which suggests that alterations in normal scapular kinematics occur within this range. Therefore, arm elevation angles at 60°, 90° and 120° relative to the trunk were chosen to analyze scapular kinematics in this study.

3.8 Data Analysis
Separate two–way mixed model ANOVA were carried out for arm elevation (phase 1), arm lowering (phase 2) and for Phase 1 and 2 combined, for all 3 tasks. ANOVA factors were Group (low, high) and Arm Elevation Angle (60°, 90°, 120°). Scapula IR, UR and Tip were the dependent variables. If the subject did not raise their arm through the full ROM, the maximum arm elevation angle was selected instead of 120°.
CHAPTER 4
OBESITY AND ROTATOR CUFF TENDONITIS

Abstract: Obesity has been correlated with increased incidence of pain and limited range of motion at the shoulder. Rotator Cuff Tendonitis (RCT) is one of the most common ailments of the shoulder joint. The objective of this study is to determine the correlation between Obesity and Rotator Cuff Tendonitis. The study consisted of 2 parts: 1) Ex post facto analysis of the Medical Expenditure Panel Survey (MEPS) database to examine the relationship between BMI and RCT and 2) Comparison of 3D scapular kinematics between obese individuals and a non-obese control group during three separate activities: raising and lowering their arm without a weight; with a three pound dumbbell; and when reaching behind their neck. A total 910 RCT cases were reported in the 2004 MEPS database, 50.6% of cases were found in people with BMI more than 27. Chi square frequencies among BMI and RCT cases reported in the database were found to be different and statistically significant at p= 0.05. The kinematic analysis demonstrated statistically significant differences between groups for upward rotation of the scapula during arm raising and lowering in all 3 activities. Between group differences were significant for scapula tipping for unweighted elevation and reaching behind the neck. These findings support a relationship between obesity, RCT, and shoulder motion.
Introduction

There has been a rapid escalation in the percentage of obese population in the United States over the past 20 years. Obesity prevalence has doubled between 1980 and 2002 in adults aged 20 years or older\textsuperscript{3,4}. The prevalence of obesity increased from 30.5\% to 32.2\% among adults above the age of 20 years between 1999-2000 and 2003-2004 alone\textsuperscript{5}. The rate of increase in the prevalence of clinically severe obesity (BMI>40) has been faster than the rate of increase in the prevalence of moderate obesity (BMI; 30-40) among adults in the United States between 2000 and 2005.\textsuperscript{6}

Obesity has been documented as a possible risk factor for upper extremity musculoskeletal pain and disability\textsuperscript{35-37} for various reasons. Increased prevalence of vascular conditions such as atherosclerosis, hypertension and diabetes has been found in people with a high body mass index\textsuperscript{7-9}. Presence of these conditions decreases the blood supply to various parts of the body. Decreased blood supply to the rotator cuff tendons, particularly the supraspinatus could increase the risk of developing RCT.

The obese population has also been documented to adopt greater flexion positions at the thoracic and pelvic levels while performing standing tasks\textsuperscript{38}. Exaggerated flexion postures have been associated with abnormal scapular kinematics\textsuperscript{39} possibly lowering the threshold for developing rotator cuff tendonitis\textsuperscript{30}.

Weakness and early fatigue of muscles are common complaints in the obese\textsuperscript{4}. These complaints are associated with of lack of exercise and sedentary lifestyle in the obese\textsuperscript{4,8,10}. The increased mass of the upper extremity may create greater loads the already weakened and fatigued rotator cuff muscles and contribute to abnormal scapular
kinematics. Microtrauma to these compromised muscles via mechanical compression while performing daily activity may then result in RCT\textsuperscript{28}.

Altered scapular kinematics has been reported in patients with rotator cuff injuries\textsuperscript{21,31-34}. Abnormal position or orientation of the scapula during arm elevation negatively affects the subacromial space and results in impingement of rotator cuff tendons. Lukasiewicz et al\textsuperscript{31} found lack of posterior tilting and excessive superior translation of the scapula during shoulder abduction in patients with shoulder impingement. Normally, posterior tilting of the scapula prevents excessive compression of the tendons in the subacromial space with arm abduction\textsuperscript{16}. Loss of posterior tilting results in a relatively anteriorly tilted scapula which narrows the subacromial space and may contribute to impingement and inflammation of the rotator cuff tendons\textsuperscript{21}. Weakness or early fatigue of the rotator cuff muscles because of impingement or inflammation results in excessive superior translation of the scapula\textsuperscript{31}. A decreased upward rotation\textsuperscript{32} of the scapula or increased internal rotation of the scapula\textsuperscript{32,33} during arm elevation may also result in subacromial space reductions\textsuperscript{32} and impingement of the rotator cuff tendons\textsuperscript{32-34}.

The purposes of this study were to examine the relationship between Adult BMI and RCT and to compare the 3-dimensional scapular kinematics in a group of obese individuals with a non-obese control group.

4.1 Methods:

Objective 1: Medical Expenditure Panel Survey Overview

The Medical Expenditure Panel Survey (MEPS) is a large scale survey examining the frequency of utilization and the cost of health services\textsuperscript{57}. The survey collects data
from a nationally representative subsample of participants of the surveys conducted by National Center for Health Statistics via Computer assisted personal interviewing (CAPI). The survey is divided into two major components, a Household Component and an Insurance Component (IC). The IC collects detailed data associated with insurance plans offered by different employers to their employees, whereas the HC collects information at the household level about the health status, demographics, health conditions, and access to care for both families and individuals. This study examined data from the HC component only.

**Objective 2: Subject selection**

Volunteers were invited to participate by posting flyers in Atwell Hall, location of the School of Allied Medical Professions, and by personally inviting students in various graduate programs at The Ohio State University. Subjects were included if they were above the age of 18 and without current shoulder pain or a history of shoulder surgery in the dominant shoulder. The study was approved by the Institutional Review Board (IRB) on human subjects at Ohio State University. Informed consent was obtained from all subjects. A single investigator collected all the data.

4.2 Instrumentation

**Objective 1: MEPS data files**

In the MEPS data files each individual is assigned a Person ID (PID) and each household a Dwelling Unit ID (DUID). Both these variable have been combined to form another identifying variable, DUPERSID, which is unique for each individual in all data.
files for a calendar year. In all the data files, data for a person is missing if the question was skipped during the interview or if a question was unanswered by the person. Full-year Consolidated Data file contains person-level data such as the BMI of an individual for one calendar year. A medical conditions file reports the various medical conditions and medical procedures for each PID using the World Health Organization (WHO) designated International Statistical Classification of Diseases and Related Health Problems (ICD) codes. Multiple medical conditions for the same individual are reported as multiple cases in the same data file. The latest year for which complete data files are available on the website was 2004.

**Objective 2: Scapular kinematics**

The Flock Of Birds (FoB) electromagnetic motion capture system (*Innovative Sports Training Inc, Chicago, IL, USA*) was used to determine the 3D orientation of the scapula at different angles of arm abduction. The instrument consists of a high frequency electromagnetic transmitter and 4 sensors. Three sensors are placed on the subjects’ skin over the segment to be analyzed. Manually palpated anatomical landmarks can be digitized using a fourth sensor attached to a stylus. Digitization leads to anatomically based axis systems for each segment. The orientation of each segments axis system is interpreted relative to the transmitter and transposed to be described relative to an adjacent segment. Milne et al\textsuperscript{62} have reported this instrument to have less than 2% error when used in the range of 22.5-64.0 cm. Electromagnetic systems have been reported to be valid and reliable for studying 3D motion of the scapula in previous studies\textsuperscript{32, 34,63}. 

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Other variables measured included individual’s 1) height, 2) weight, 3) arm skin-fold thickness, and 4) thoracic kyphosis during normal stance. Height and weight were used to calculate the subject’s BMI. Skin fold measurements using a calibrated *Lange* skin-fold caliper (Cambridge Scientific Industries Inc. Cambridge, MA) were taken to determine if the subcutaneous tissue mass of the arm in the obese group was more than that of the lean group. To find out if any differences in scapular kinematics may be related to postural differences between the 2 groups, thoracic kyphosis during normal stance was measured. To measure subject height and weight, a mechanical scale with a built-in ruler was used. The biceps and triceps skin-fold measured using a caliper. Skin-fold thickness has shown to be positively correlated with obesity in previous studies $^{64}$. Vertical skin folds were measured halfway between greater tuberosity and the center of cubital fossa for biceps and halfway between the olecranon and acromion process of the scapula for triceps.

The Index of Kyphosis (IK) for the thorax was measured with a flexible ruler. The ruler was placed on an individual’s back with one end at the C7 vertebrae and molded to the contour of the entire thoracic spine. The curve is then traced on graph paper and the IK calculated using the formula thoracic width (TW) divided by thoracic length (TL) and the result multiplied by 100$^{61}$.

4.3 Procedure

*Objective 1: MEPS data preparation*

To extract the information needed for this study, the 2004 Full-year consolidated file was linked to the 2004 Medical conditions file with the common DUPERSID
variable. The ICD9 codes 726, 727 or 840 were used to identify patients with RCT. The data were processed to eliminate missing values for BMI and ICD9 codes. BMI was recoded into categorical variables. Group 1 included individuals with BMI <22.9, Group 2 with BMI between 23 and 26.9, Group 3 included individuals with BMI ≥27. Only the cases with the required ICD9 codes 726, 727 or 840 were selected for analysis.

**Objective 2: Data collection**

Data were collected for the subjects’ height and weight, triceps and biceps skin–folds, and amount of thoracic kyphosis.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Group 1 (n=13)</th>
<th>Group 2 (n=12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Female</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>Age (yrs)</td>
<td>27±2.3</td>
<td>30±6.3</td>
</tr>
<tr>
<td>Weight (lbs)</td>
<td>130.8±17.7</td>
<td>197.5±49.7</td>
</tr>
<tr>
<td>Height (inch)</td>
<td>66 ±3.4</td>
<td>66.4±4.3</td>
</tr>
</tbody>
</table>

*Table 4.1 –Subject demographic data*

Data for orientation of the scapula and humerus relative to the trunk were collected using the FoB for only the dominant side shoulder. Three sensors for motion
analysis were taped to the subjects’ skin over the sternum, acromion, and distal humerus with hypoallergenic tape. Data were collected during three separate tasks: Task 1- raising and lowering their arm in the scapular plane without a weight; Task 2-raising and lowering the arm in the scapular plane with a three pound dumbbell; and Task 3-reaching behind their neck. The subjects were asked to perform 5 repetitions for each task. Movements in the scapular plane were performed with the thumb pointing up. Subjects self selected the motion as they reached behind their neck. For all the three task subjects self selected the speed of the motion.

4.4 Data Analysis

Objective 1: MEPS data analysis

A total of 32,737 persons were interviewed in the year 2004. Linking the full year consolidated file with the medical condition file resulted in a total of 106,738 cases. Data were analyzed using the SPSS 15.0 software (SPSS Inc, Chicago, IL). A Chi–Square test was used to analyze the frequency of RCT across BMI groups at a criterion level of $P<0.05$.

Objective 2: Kinematic Analysis

Data from the second, third and fourth repetitions were analyzed. For kinematic analysis, the dependent variables were i) Scapular Upward Rotation (UR) ii) Scapular Internal Rotation (IR) and iii) Scapular Tipping (Tipping). BMI group (low, high) and arm elevation angle relative to the trunk ($60^\circ$, $90^\circ$and $120^\circ$) were the independent variables. Patients with RCT usually complain of pain between $60^\circ$ - $120^\circ$ of humeral
abduction. This suggests that any alterations in normal scapular kinematics occur between these angles. Therefore, arm elevation angles at 60°, 90° and 120° relative to the trunk were chosen to analyze scapular kinematics in this study.

To analyze the data, 2 groups were created: Group 1 = BMI <23 and Group 2 = BMI >27. Subjects with BMI ranging from 23-27 were excluded as it has been noted that the standard BMI cut off of 25 used for categorizing overweight subjects often results in muscular subjects being misclassified. One-tailed T-tests were carried out to determine if between group differences were significant for triceps and biceps skin-folds and also IK.

Separate two–way mixed model ANOVA were carried out for arm elevation (phase 1), arm lowering (phase 2) and for Phase 1 and 2 combined, for all 3 tasks. ANOVA factors were Group (low, high) and Arm Elevation Angle (60°, 90°, 120°). The highest point in the ROM was selected if the patient did not raise their arm to a 120°.
4.5 Results:

*Objective 1: MEPS Results*

<table>
<thead>
<tr>
<th>Age</th>
<th>RCT Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>18.1-20</td>
<td>35</td>
</tr>
<tr>
<td>20.1-30</td>
<td>79</td>
</tr>
<tr>
<td>30.1-40</td>
<td>88</td>
</tr>
<tr>
<td>40.1-50</td>
<td>224</td>
</tr>
<tr>
<td>&gt;50</td>
<td>481</td>
</tr>
</tbody>
</table>

*Table 4.2: Cross tabulation of Age Vs Number of RCT cases found in MEPS database*

<table>
<thead>
<tr>
<th>BMI</th>
<th>ICD-9-CM CODE FOR CONDITION</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>726</td>
<td>727</td>
</tr>
<tr>
<td>0-22.9</td>
<td>77</td>
<td>45</td>
</tr>
<tr>
<td>22.9-26.9</td>
<td>103</td>
<td>74</td>
</tr>
<tr>
<td>&gt;27</td>
<td>215</td>
<td>133</td>
</tr>
<tr>
<td>Total</td>
<td>414</td>
<td>271</td>
</tr>
</tbody>
</table>

*Table 4.3: Cross tabulation of BMI Vs ICD9 Codes found in MEPS database*
A total of 910 cases for RCT were recorded in the year 2004. RCT cases were found to be more common in the subjects above the age of 50 (Table 4.2). As evident from table 4.1, 50.6% of the cases were reported in people with BMI greater than 27. Chi-Square analysis between BMI and RCT cases reported in the database was found to be statistically significant at p= 0.05. (Table 4.4).

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>df</th>
<th>Asymp. Sig. (2-sided)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson Chi-Square</td>
<td>13.590</td>
<td>6</td>
<td>.035</td>
</tr>
<tr>
<td>Likelihood Ratio</td>
<td>13.127</td>
<td>6</td>
<td>.041</td>
</tr>
<tr>
<td>N of Valid Cases</td>
<td>910</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4.4: Chi-square results for BMI and RCT cases for MEPS database

Objective 2: Human subject analysis

A total number of 40 subjects were tested. The BMI ranged from 18.4-41.3. After excluding data from individuals with BMI between 23-27, the number of subjects in Group 1 was = 12 and in Group 2 was = 13. The mean biceps and triceps skin–fold thickness for Group 2 was greater than the mean triceps and biceps skin-fold thickness for Group 1 (Table 4.5) The difference was statistically significant at p=0.05 level. The mean IK for Group 2 slightly higher than of Group 1, however the difference was not statistically significant. (Table 4.4)
The results from the separate 2 way ANOVA did not show any statistically significant differences between groups for IR of the scapula in any of the tasks. Statistically significant differences between groups for UR of scapula were noted for almost phases and all tasks. Between group differences were statistically significant for tipping for Task 1 and Task 3 (Table 4.6). The range of standard deviation for each variable across all three tasks in the two groups is reported in Table 4.7.

### Table 4.5 Average skin folds and IK for Group 1 and Group 2

<table>
<thead>
<tr>
<th></th>
<th>Group 1 (mm) ± SD</th>
<th>Group 2 (mm) ±SD</th>
<th>T-test results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biceps</td>
<td>8.3± 6.3</td>
<td>22.5± 11.7</td>
<td>0.0009*</td>
</tr>
<tr>
<td>Triceps</td>
<td>21.8±10.06</td>
<td>34.3±11.8</td>
<td>0.005*</td>
</tr>
<tr>
<td>IK</td>
<td>12.7± 3.6</td>
<td>13.5± 3.2</td>
<td>0.21</td>
</tr>
</tbody>
</table>

*statistically significant result

The results from the separate 2 way ANOVA did not show any statistically significant differences between groups for IR of the scapula in any of the tasks. Statistically significant differences between groups for UR of scapula were noted for almost phases and all tasks. Between group differences were statistically significant for tipping for Task 1 and Task 3 (Table 4.6). The range of standard deviation for each variable across all three tasks in the two groups is reported in Table 4.7.
Fig 4.1. Average scapular upward rotations (UR) and tipping (tip) for non-obese group (1) and obese group (2) at 60, 90 and 120 for Task 1, Task 2 and Task 3.
Table 4.6: Differences in scapular kinematics by varying tasks

<table>
<thead>
<tr>
<th>Variable</th>
<th>Task 1 (deg)</th>
<th>Task 2 (deg)</th>
<th>Task 3 (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scapular IR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group</td>
<td>0.42</td>
<td>0.81</td>
<td>0.16</td>
</tr>
<tr>
<td>Humeral angle</td>
<td>0.42</td>
<td>0.27</td>
<td>0.53</td>
</tr>
<tr>
<td>Group X angle</td>
<td>0.98</td>
<td>0.83</td>
<td>0.84</td>
</tr>
<tr>
<td>Scapular UR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group</td>
<td>0.002*</td>
<td>0.0001*</td>
<td>0.0003*</td>
</tr>
<tr>
<td>Humeral angle</td>
<td>0.00*</td>
<td>0.00*</td>
<td>0.00009*</td>
</tr>
<tr>
<td>Group X angle</td>
<td>0.016*</td>
<td>0.08</td>
<td>0.78</td>
</tr>
<tr>
<td>Scapular Tip</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group</td>
<td>0.006*</td>
<td>0.055</td>
<td>0.0007*</td>
</tr>
<tr>
<td>Humeral angle</td>
<td>0.813</td>
<td>0.9</td>
<td>0.94</td>
</tr>
<tr>
<td>Group X angle</td>
<td>0.654</td>
<td>0.8</td>
<td>0.81</td>
</tr>
</tbody>
</table>

*p<0.05

Table 4.7: Mean ± Standard deviations for each variable for the two groups

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group 1 (deg) Mean ± SD</th>
<th>Group 2 (deg) Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>IR</td>
<td>35.7±16.13</td>
<td>36.4±16.17</td>
</tr>
<tr>
<td>UR</td>
<td>23.3 ± 10.3</td>
<td>31.7 ± 16.7</td>
</tr>
<tr>
<td>Tipping</td>
<td>-10.3 ± 13</td>
<td>-16.7 ± 17.8</td>
</tr>
</tbody>
</table>

Table 4.7: Mean ± Standard deviations for each variable for the two groups
4.6 Discussion

We used BMI to define obesity in our study. BMI was a suitable criterion to define obesity in our study as a strong correlation between BMI and musculoskeletal conditions like back pain and osteoarthritis have been already reported. Scapular kinematic data from subjects with BMI $\leq 23$ and $\geq 27$ were compared. As mentioned before we excluded data from individual with BMI between 25 and 27. This allowed us to include normal and overweight subjects in our study and exclude any muscular subjects which might have been misclassified with the BMI cut off of 25.

**MEPS Data Results**

RCT was found to be more common in older individuals. This result is in agreement with the work of Tempelhof et al. Degeneration of tendons with aging makes the incidence of RCT higher as individuals get older. This association has already been studied and was found to be true for RCT cases reported in the MEPS database.

We found a statistically significant increase in the frequency of RCT with higher BMI groups in the HC of the MEPS database. The numbers of RCT cases were significantly greater in the group with BMI more than 27. Our results are in agreement with those of Wendelboe et al where the authors used shoulder repair surgery as an indicator of RCT and found subjects with BMI $\geq 35$ to have had the greatest number of shoulder repair surgeries among BMI groups. As mentioned before, not all patients with RCT need surgery. Our results indicate that RCT is more common in subjects with BMI $> 27$. Obese subjects are more likely to suffer from cardiovascular conditions and the risk of developing these conditions increases with increased BMI. Conditions such as
atherosclerosis and hypertension cause decreased blood supply to different parts of the body. Supraspinatus has been documented to have an avascular zone near its insertion and is the most common rotator cuff muscle involved in RCT. Decreased blood supply to the rotator cuff tendons due to presence of vascular conditions may increase the risk of developing RCT. It may also hasten the progress of RCT leading to tears in the muscle. Wendelboe et al may have found a large number of surgeries in the obese group possibly because of increased severity of RCT in the group. Although as of date there is no evidence to indicate a relationship between obesity and progression of RCT; it is our thought that more arm weight and presence of vascular conditions in the obese together may worsen RCT to rotator cuff tears which may have required surgical treatment.

We chose MEPS database for our study because the data are collected from a nationally representative sample. The MEPS-HC is noted to be an accurate source of national estimates of insurance coverage. However, the use of the MEPS data to find correlation between health conditions and anthropometric measures may raise some concerns. First, the MEPS data is self reported and recall bias is one of the most common problems with self reported data. The subject may not remember incidents or may not report it at the time of interview. In surveys such as MEPS, one person reports the incidents of the entire family. Sometimes, a respondent may not recall the events in lives of other family members; in a large or complex family the respondent may not be well informed. This may result in under-reporting of certain events, in this case RCT.

Another problem that may arise with self-reported data is that the subjects may report an event incorrectly. Some subjects may not report certain disabilities or medical conditions. Personal variables such as height, weight, financial income reported by the
individual may differ from the actual. In our study, we analyzed the correlation between RCT and obesity. RCT is a very common musculotendinous condition and patients should not feel hesitant to report this condition. BMI provided for each person in the database has been calculated from the self-reported weights and heights. However, according to a study by Palta et al, majority of the individuals were found to underreport their weight. These subjects if suffered from RCT will be included in the non-obese group. However, all these errors imply that the results of this study may only be underestimated.

Another limitation with our analysis is that we did not analyze the missing data. Out of a total of 106,738 cases, 2972 cases were missing information about BMI or ICD9 codes. Thus, data was missing for less the 0.03% of the total cases. This should not affect the results of our study significantly.

The second part of our study was designed to examine a potential cause for this correlation between high BMI and RCT. We hypothesized that increased arm mass would lead to altered scapular kinematics in the obese group of subjects. In our comparison of 3D scapular motion between an obese group with BMI>27 with that of a lean group with BMI< 23 across three tasks; we found significant differences for scapular upward rotation and scapular tipping. The obese group was found to have reduced posterior tipping of the scapula with humeral elevation for Task 1 and 3. We did not find a statistically significant difference in scapular tipping for task 2 but came close with p=0.055. This makes it evident that scapular kinematics in the obese is different from that in non-obese. There is more upward rotation and less posterior tipping of the scapula in the obese as during standing arm abduction. The more anteriorly placed scapula decreases the
subacromial space and result in impingement of the rotator cuff tendons.\textsuperscript{30-33}. Patients with impingement have been found to have similar changes in scapular kinematics\textsuperscript{32}.

There was greater upward of the scapula in the obese group than the non-obese group. This is different with results reported by Ludewig et al\textsuperscript{33} and Borstad et al\textsuperscript{34}. They compared 3D scapular kinematics between subjects with and without impingement and found decreased upward rotation and reduced posterior tipping of the scapula\textsuperscript{33,34}. Lukasiewicz et al\textsuperscript{32} reported increased upward rotation during humeral elevation along with decreased posterior tipping of the scapula in subjects with impingement. The increased upward rotation was thought to be a compensatory mechanism for decreased posterior tipping of the scapula. While the more anteriorly placed scapula reduced the subacromial space, impinging the rotator cuff tendons, increased upward rotation may increase the subacromial space and relieve impingement signs. Recently however, cadaver studies by Karduna et al\textsuperscript{68} directly studied the contact forces in the subacromial space and found that increased scapular upward rotation resulted in a decrease in the subacromial space\textsuperscript{68}.

Increased upward rotation of the scapula has also been reported in subjects with fatigue of the shoulder by Ebaugh et al\textsuperscript{69-70} and McQuade et al\textsuperscript{71}. In our study we recorded 3D scapula motion as the subjects performed humeral abduction in the scapular plane and reaching behind the neck. Scapular muscles play an important role in humeral elevation\textsuperscript{70}. Ebaugh et al found increased upward rotation of the scapula with fatigue of external rotators\textsuperscript{69}. External rotator muscle weakness has also been documented in subjects with rotator cuff impingement\textsuperscript{72}. It is possible that weakness of external rotators in subjects with impingement resulted in increased upward rotation in the studies where it
has been reported. Increased upward rotation noted in our study may also be a result of muscle weakness. Obese subjects may have general muscular weaknesses because of lack of exercise. Increase arm mass can cause increased loading of the shoulder muscles leading to early fatigue of muscles, predisposing the muscles to injury and inflammation.

In another study, McQuade et al found fatigue of scapular muscles with shoulder abduction\textsuperscript{71}. They noted increased upward rotation of the scapula with fatigue of muscles stabilizing the scapula. It is possible that increased motion of the scapula with shoulder abduction found in our study be a result of weakness and fatigue of these scapula stabilizers. Any abnormal motion of the scapula will increase stress on the rotator cuff muscles and the risk of RCT in obese.

We used FoB to determine the motion of scapula in our study, which collects data for movement of the bones by taping sensors to the overlying skin. These sensors may not accurately detect the motion of the underlying scapula in obese subjects due to increased subcutaneous tissue. This may lead to errors due to skin-slip in our recordings of scapular motion in obese subjects. However, there is no current evidence that skin-slip error is greater in obese subjects and thus it has not been accounted for in our analysis.

We found both triceps and biceps skin-fold thickness to be greater in the obese group than the lean group. This is in agreement with our assumption that the mean upper extremity mass in a group of obese individuals is greater than that of a lean group. Thus, rotator cuff muscles along with other shoulder muscles have a greater demand in an obese individual because of the increased mass of the arm. This could cause also result in early fatigue of the muscles and altered scapular kinematics including increased upward rotation of the scapula in our study. Abnormal movement of the scapula may in turn
create greater stresses on the rotator cuff muscles. Thus, a vicious cycle is set up, putting the obese individual at a greater risk of developing RCT.

There was no significant difference between mean ages for the two groups. Both the groups consisted of healthy individuals and were fairly young. Because RCT incidence is known to increase with age, it is possible that scapular kinematic differences in the groups could be reflective of age differences. However, the deviation in movement of the scapula in the obese group compared to a non-obese group of similar age suggests otherwise and may indicate that obesity may predispose individuals to development of RCT earlier than what may occur with aging alone.

We did not find any significant difference for thoracic kyphosis in neutral stance between the 2 groups. In contrast, Gillear and Smith found a significant correlation with the posture of the thoracic segment. However, they studied the trunk forward flexion motion while the individuals performed a standing task unlike our study where index of kyphosis was calculated with the individual in normal standing. Obese individual often have fat stored in the abdominal area which results in the abdomen protruding anteriorly. This could be a reason why the authors noted greater flexion at the thoracic spine while reaching forward to perform a functional task. The difference in thoracic kyphosis of an obese individual may occur only as they perform a dynamic activity and not at rest. In our study, the subjects were asked to stand normally, with their hands by their side while the kyphosis was measured.

Our results indicate that scapular kinematics in the obese are altered. The decreased posterior tipping of the scapula as compared to the non-obese group suggests that they are at greater risk for RCT than a non-obese. Despite the discrepancy regarding
scapular upward rotation in subjects with shoulder impingement reported by different authors, it is definite that scapular motion in patients suffering from impingement is not normal. We found that upward rotation of the scapula in the obese subjects is also abnormal.

4.7 Conclusion

Our study shows that there are higher rates of RCT as BMI increases, and that scapular kinematics in the obese population are altered. The alterations in movement are similar to those seen in groups of subjects with impingement. Fatigue or excessive loading of the rotator cuff muscles because of increased arm mass in an obese individual could lead to rotator cuff injuries like RCT. These changes may be accompanied with vascular conditions in the obese which decrease the blood supply to the rotator cuff tendons. Further detailed studies which include data about an individual’s medical conditions and upper extremity muscle strength will perhaps be useful in determining the precise cause for altered scapular kinematics observed.
CHAPTER 5

DISCUSSION

We used BMI to define obesity in our study. BMI was a suitable criterion to define obesity in our study as a strong correlation between BMI and musculoskeletal conditions like back pain\(^6^4\) and osteoarthritis\(^6^5\) have been already reported. Scapular kinematic data from subjects with BMI ≤ 23 and ≥27 were compared. As mentioned before we excluded data from individual with BMI between 25 and 27. This allowed us to include normal and overweight subjects in our study and exclude any muscular subjects which might have been misclassified with the BMI cut off of 25.

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