Investigating the Biological Composition and Injurious Tendencies of the Rotator Cuff Muscles

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ABSTRACT

The construction of our human anatomy is one of great importance. In the grand scheme of the rotational torque that our skeletomuscular body exerts, one such key structure is the Rotator Cuff Muscles. To function as a biologically sound component of the human body, the muscular composition of the Four Major Muscles[3]: the Supraspinatus, Subscapularis, Teres Minor, and the Infraspinatus. I explored the muscular composition and substance matter of each of these 4 crucial muscles of the Rotator Cuff. Through the various connections between the movement, location (relative to the midline of the body), and the composition of tissue, an apparent connection between the muscular damage in each of these listed muscles can be observed as well.

Overview

The Rotator Cuff Muscles provide a great deal of movement, agility, and freedom for the human body. The Rotator Cuff Muscles are composed of the Supraspinatus, Subscapularis, Teres Minor, and the Infraspinatus. Accordingly, each of these muscles are defined by their anatomical position.

One important distinction and terminology is the *tuberosity*[4]. This denomination identifies *an elevation (or projection), specifically one of which is where a muscle attaches to the bone.*

- The Supraspinatus Muscle[3] is located superiorly to the spine of the shoulder blade and inserts itself upon the greater tuberosity of the shoulder blade.
- The Infraspinatus Muscle[3] originates inferiorly to the spine of the scapula in the infraspinatus depression, or *fossa*. Superiorly, the infraspinatus muscle attaches itself to the posterior aspect of the greater tuberosity of the humerus.
- The Teres Minor Muscle[3] originates alongside the border of the lateral scapula and inserts itself onto the inferior portion of the greater tuberosity of the humerus.
- The Subscapularis Muscle[3] originates from the anterior aspect of the anatomical position, specifically of the scapula, directly anterior to the rib cage. The subscapularis muscle tapers off to the lesser tuberosity of the humerus.

Injuries to the shoulder are often caused by stress to the Rotator Cuff Muscles. Most shoulder muscles and tendons involved in the mobility of the Rotator Cuff Muscles are often injured due to overuse[5]: throwing, shooting, or respective circular and/or overhead movement leads stability and inflammation. These common symptoms of excessive shoulder girdle movement can lead to the *impingement syndrome*, in which the acromion process is subjected to intense outward pressure and swelling. The Rotator Cuff Muscles themselves are vulnerable to many of the following syndromes, even with postural neglect.

Throughout this paper, the employment of scientifically concurred protocols to articulate the muscle fiber lengths, sarcomere length-joint angle, and the differing PCSA will be analyzed to conclude the muscle-shoulder function in depth. The areas which of painful injuries at the Rotator Cuff Muscles will be thoroughly analyzed.

Investigation

To qualify the construction of the Rotator Cuff Muscles as the objective, a fundamental manner of muscle architecture and the defining standpoint must be established. This is concurrently done through establishing a similar quantifying system established by the method of Roy & Sacks[6].

Through this enforced method, the criteria of which the muscular composure can be fully analyzed is through the force, velocity, and displacement proportions regarding the movement and enduring architectural design. In addition, the sequence of variables ought to be discussed[6]: muscle weight, fiber length, average sarcomere length, and approximate angle of supination for the muscular structure.

Thereby, methods of measurement and analysis are instituted. Before, we must identify the primary attribute of each node of measurement & its device's operation in the study. The weight of the muscles of the Rotator Cuff hints towards the weight of the proximal insertions of each of the three muscles to the distal connection with a ligament/bone of the respective muscle. Likewise, as the name implies, the muscle length along with surface pennation angles are objectively quantitative and are measured based on the selected samples of *cadavers*[7].

In order to begin the analysis, we must examine the proportions of the cadavers. The body metrics necessary to complete this analyzation include a humeral head differential in measurement of 4.42 cm ± 0.37 cm, a sample size of male: female ratio of shoulder compartments of 5:5, along with an extended age of 88 ± 13 years. These 10 fresh cadavers were observed by the previously mentioned *Roy and Sacks* discussion for clarity.

Achieving maximum clarity before the due measurement process calls for the specimen to be righteously detailed. This entails that the cadaver's humerus will be processed with a transversal cut approximately distal to the insertion of the deltoid, allowing for the removal of nearby skin tissue and the overlying deltoid muscle. Additionally, to keep the Rotator Cuff Muscles fully intact, the scapula and proximal humerus structures were freed from the respective chest wall, positioned in the anatomical position (a lack of/no abduction, adduction, flexion, and extension to the nearest degree of measurement). Diluting the storage supplement in a 10% buffered solution of formaldehyde allows the cadaver to resist pH change in a specific, closed environment.

Following the placement of the deltoid tuberosity of the humeral shaft into a similar anatomical plane as that of vertebral column of the scapula (distal to the original orientation). The supraspinatus muscle and the subscapularis muscle are surgically exposed by cutting open the specimen's coracoid process, medial to the acromion process, which holds the connective tissue and area between the acromioclavicular joint, the medial aspect of the plane which is being analyzed.

Each muscle is from the respective tendinous attachments, although there will be no difference in the approach to calculating the sarcomere length, as the detachment of the fascicles doesn't alter the measured length. These [10 different] cadaver samples, singularly the muscular components, were left to be soaked in a phosphate solution, specifically, buffered saline. This provides an additional chelate[8] effect, as although it is commonly identified as an ionic substance that holds complex chains of chemical bonds, it acts as a homogenous catalyst. The resulting chemical procedure produces these individual cadavers, in which landmarks such as the Coracoid Process, and the various individual components to the Rotator Cuff Muscles are seen.
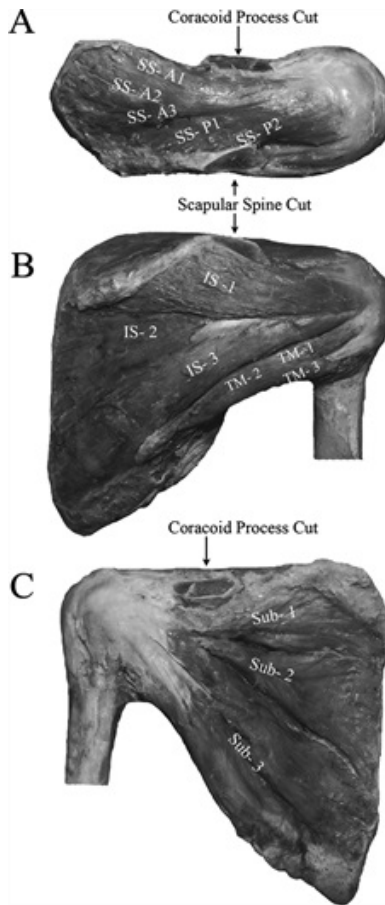
Figure 1[1]

Under these magnifications, the significance of the sarcomere number must be defined. The sarcomere[9] is the main contracted-oriented unit of muscle fiber in the skeletomuscular system, the skeletal muscle. The structure of sarcomere muscles is confined by the number of myofilaments (myosin, actin),

The thick protein filament of myofilament is identifiable through the sarcomere number, and a distinction can be found through the binding patterns:

1. *Anisotropic bands*
2. *Isotropic Bands*
3. *Z Disk*
4. *M Line*
5. *H Zone*

Using a plasma stain known as *Gomori trichome*[10,11] the skeletal muscle fibers analyzed for a longitudinal shoulder, the characteristic(s) of Isotropic Bands can be seen in figure 2.
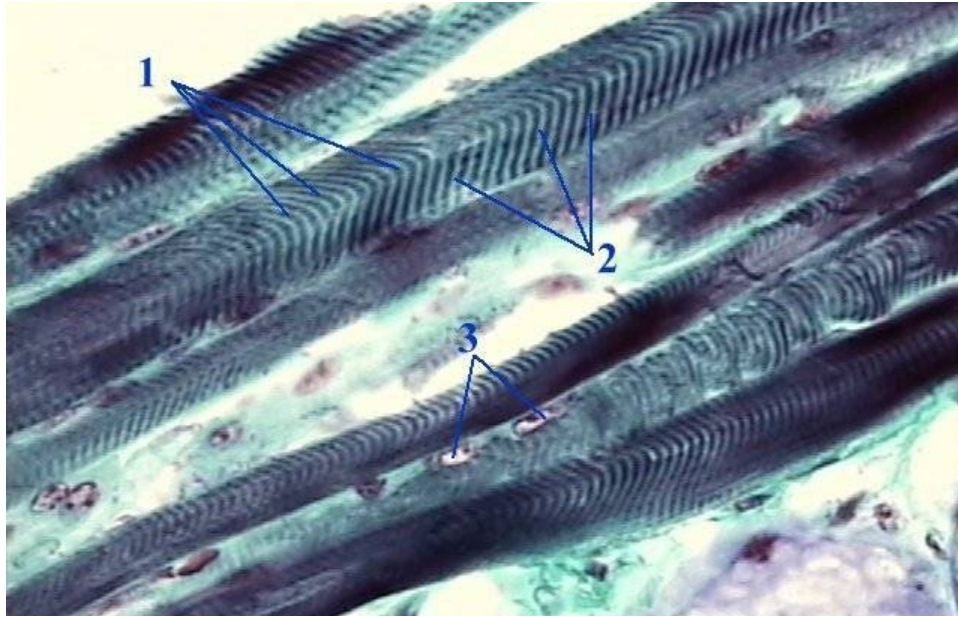
Figure 2[10,11]

Using this information, the calculations of the proceeding sarcomere number (S_n), along with the normalized fiber length, can be done with the integration of these equations:

$$S_n = \frac{L_f`}{L_s`}$$

$$L_f = L_f` \left( \frac{2.7\mu m}{L_s`} \right)$$

In this interpretation, the differentiation between L_f and L_f is where L_f is defined as the normalized (scientific) fiber length, L_f is the measured fiber length of each cadaver supplement. The specific cross physiological cross-sectional area of the muscle perpendicular to the field of [muscle] measurement is dependent[12] on the muscle volume, pennation angle, and muscle fiber length of the sample. To decipher this, the following equation[12] is implemented:

$$PCSA\ (mm^2)\ =\ \frac{M\ (g)\ g\cos(\theta)}{\rho \left(\frac{g}{m^3} \right)\ gL_f\ (mm)}$$

Findings

The discussion of the proceeding sarcomere number is done through the data that has been collected. Under magnification, the samples displayed in the earlier section were analyzed. The Regions: SS-A1, A2, and A3 of the supraspinatus were located on the anterior end, while the cadaver Region: SS-P1, P2, were located on the posterior end of the sample. Utilizing laser diffraction[19] allows the system's isolated bundles of muscle tissue to determine the sarcomere length. A technique that embodies particle-size distribution for dry dispersions, this process offers a wide measurable particle diameter range.

       The measurement of the PCSA was memorable for the fact of proportionality: the muscle's maximum body-force producing capacity is directly proportional to the value of the calculated PCSA value. Additionally, a well-kept

terminology is the relationship between the ratio of the measurement sarcomere length to the normalized muscle fiber length. For a brief comparison, the muscle(s) containing fibers spanning the length ratio of 1 ($L_f/L_m = 1$) are more scientifically identified to be excursive, while the muscle(s) containing fibers spanning ½ of the length ratio ($L_f/L_m = 0.5$), aren't identified as excursive.

To compute the relationship between the normalized muscle fiber length and the anteroposterior (AP) diameter of the humeral head, the implementation of a simple linear regression model is done. Through this method, this ratio will be successfully calculated independently of the absolute magnitude of the muscle-fiber length.

Adapted, published data was used in scope to determine the muscle excursion-joint angle functions; specifically, to define the muscle length as a function of joint angle. To determine the angle of the relative tension-joint system between each of the cadaver's muscle(s) and the glenohumeral mechanics, a simple lumped parameter model was used. Using the primary, collected data, the basic muscular architecture was found: the resting sarcomere number, average normalized fiber length (L_f), and P.C.S.A. Accordingly, the muscle fiber lengths and serial sarcomere number (S_n) were scaled to a 51-millimeter humeral head.

To accurately demonstrate the understanding of the specimen's operating joint-tension angles, the Glenohumeral joint was modeled in all transpositions of 75° medial and lateral positions (relative to internal & external rotation) to a 75° abduction in the scapular[13], essentially the scapular plane being 30° from the midline of the anatomical position. Two indicative sets of data are the muscle-length tension curve, which is symbolic of the force a muscle can generate while held at a series of lengths. The length-tension curves are generated, similarly, based on the sources of passive and active tensions. Specifically, these sources of input describe the maximum isometric force as the muscular limbs peak over their performance. In this scenario, the isometric force is representative of the various joints related to the Rotator Cuff Muscle.

The resulting findings in Figure 1 made a compelling case for the muscular weight and the length of the subscapularis and infraspinatus muscles. Out of all the muscles in the Rotator Cuff, the subscapularis and infraspinatus muscles were measured to be such. The PCSA (physiological cross-sectional area) of the infraspinatus muscle and subscapularis muscle displayed higher quantities than the other 2 muscles.

Table 1[1]

Muscle	Mass (g)	Muscle Length (cm)	L_f (cm)	L_f/L_m	L_s (μm)	S_n	Pennation Angle (degrees)	PCSA (cm²)
Supraspinatus	34.0 ± 4.3	8.5 ± 0.4	4.5 ± 0.32	0.53 ± 0.03	3.23 ±0.05	16,655 ± 1182	5.1 ± 0.6	6.65 ± 0.56
Infraspinatus	78 ± 7.5	12.2 ± 0.5	6.57 ± 0.33	0.55 ± 0.02	3.18 ± 0.06	24,332 ± 1203	1.4 ± 0.4	10.71 ± 0.95
Teres minor	21.2± 2	10.8 ± 0.6	6.09 ± 0.35	0.57 ± 0.03	2.80 ± 0.07	22,569 ± 1299	0.6 ± 0.3	3.18 ± 0.30
Subscapularis	101.8 ± 11.5	13 ± 0.6	6 ± 0.47	0.45 ± 0.02	0.45 ± 0.02	22,069 ± 1735	0 ± 0	15.53 ± 1.41

*Values are based on a standard error of 10 units; L_f = normalized fiber length, L_f/L_m = normalized fiber length/muscle length ratio, L_s = resting sarcomere length; S_n = sarcomere number; PCSA = physiological cross-sectional area

The ratio between the normalized fiber length and the muscle length ratio is seen to be proportional and close between the muscles. The Infraspinatus and the Teres minor display the highest value of the specimen, indicating that these muscles contain muscle fibers that better support excursion activity.

The results from the standard deviation model define the differences in muscle fiber length variability. Figure 2 below illustrates the regional differences in the different sectors of the Rotator Cuff Muscle's fiber length, indicating that these measurements were within 20%, aside from the inferior and superior regions of the subscapularis, which have a muscle fiber length variability proportion of 27%. The controlled data set reduced the statistical faultiness of the comparison(s) below.

Regions 1-3 reflect the Fiber Length(s) of the regions marking SS-A1 through SS-A3, and all other respective first three regions of the samples. The 4th and 5th Region reflect, on the other hand, SS-P1 and SS-P2. Conclusively, the muscle fiber length of the Supraspinatus is lower than the values of the other 3 muscles. The inferior regions of the infraspinatus and subscapularis are shorter than the remaining inferior regions of the various studied muscles.
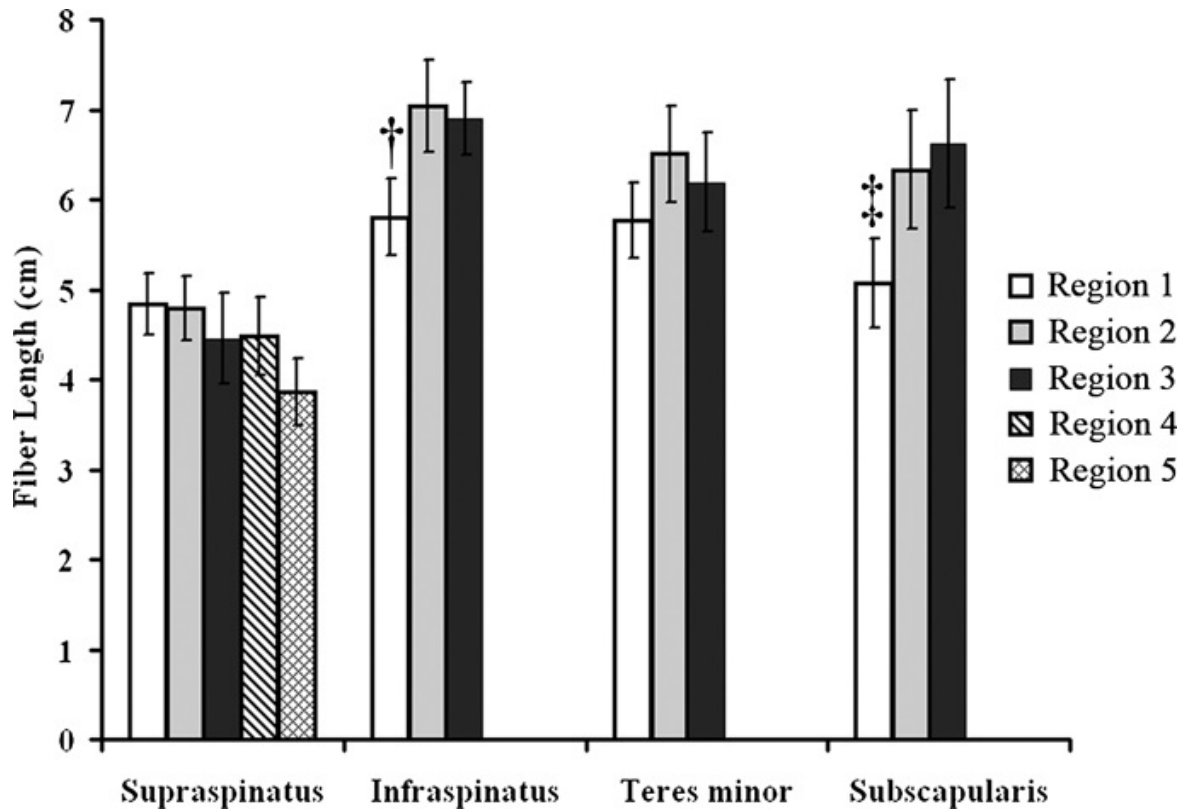

Figure 3[1]

The scaling relation between the Normalized Muscle Fiber Length as a function of the diameter of the gleno-humeral anatomical neck displayed the scaling properties were only mildly observable in the Teres minor and supraspinatus muscles. The significant regression model indicating that the *r* function did not approach 1, resulting in a scientific clarification that the skeletal muscle of each region's sample does not proportionally correlate with its respective muscle fiber length.

Analyzing the passive-tension motion of the modeled operating ranges, it deciphered that the sarcomere lengths of the supraspinatus prove to be the most sensitive to abduction motions. Likewise, the teres minor, subscapularis, and infraspinatus were most sensitive to medial-lateral motions. In comparison, the supraspinatus functioned with the least margin of increasing/decreasing values (1.95 - 3.39 μm), and in increasing order, the margin of range is teres minor, infraspinatus, and the subscapularis muscle.

Table 2[1]

Muscle	Slope	Y-intercept	r^2
Supraspinatus	1.94 ± 0.67	-4.06 ± 2.96	0.513
Infraspinatus	1.42 ± 0.84	0.32 ± 3.67	0.265
Teres minor	2.27 ± 0.68	-3.93 ± 3.01	0.583
Subscapularis	1.75 ± 1.26	-1.78 ± 5.58	0.195

*Significant regression model fit; values are displayed based on a standard deviation of 10 specimens.

The length-tension curve, as mentioned previously, is a representation of the force the muscle can generate at specific, discrete lengths. These coordinated muscles contained the upper echelon of generating maximum force capacity (>75%) due to having a serial sarcomere number (S_n) in the range of 1.5 µm and 3.25µm. This proves that despite the textural and length-based differences in measurements, the passive tension distributions were far more in common compared to the active tension distribution.
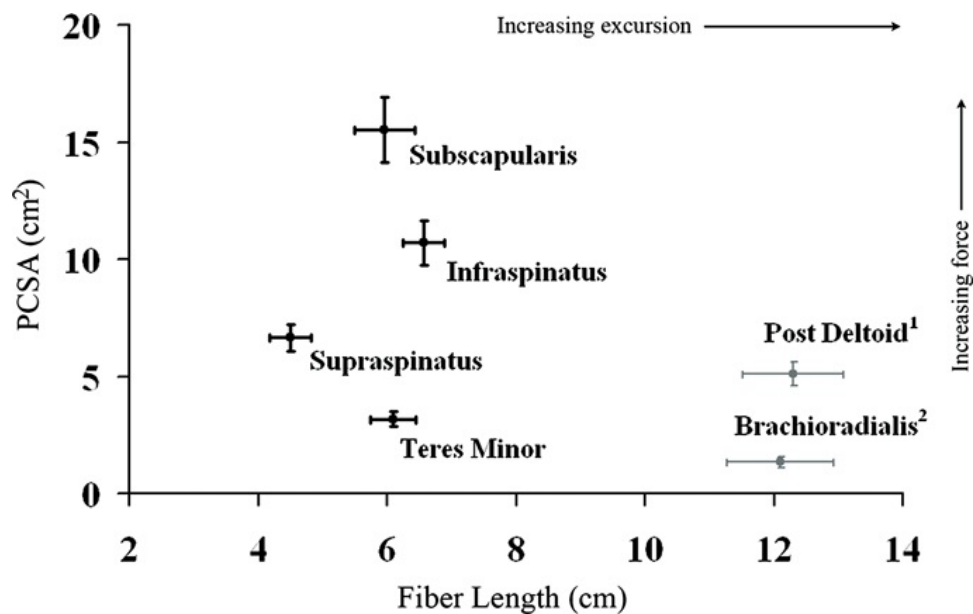

Figure 4[1]

The Figure displaying the scatter plot illustrates the relationship between the Fiber Length (cm) to the PCSA (cm²). While the contributed 43% of the Rotator Cuff's active tension, the supraspinatus contributed 21%, and the teres minor muscle contributed 8% of the total active tension. The comparison of the Rotator Cuff muscle's short fiber length and large PCSAs with *other* muscles in the upper extremities (Brachioradialis, Post Deltoid) indicate that these Rotator Cuff muscles provide substantial role of stabilizing[20] the glenohumeral joint.

Conclusively, these data figures substantialize the role of the Rotator Cuff Muscles as stabilizers, with specific muscle enforcing as both shoulder stabilizers for the glenohumeral joint and providing torque and force to the body's movement. Clinically, the next course of action would be to explore the injurious tendencies of the Rotator Cuff muscles, with the implications set that small surgical changes to the Rotator Cuff muscles reflect drastic functionality changes in the shoulder.

Assessment

Injuries to the rotator cuff muscles analyzed in this section of the paper. Through meticulous research oriented around *keywords* such as full-thickness rotator cuff tears, operative and surgical indication, and further indication for surgical and treatment outcome.

The determined variables that influence the nonoperative or operative treatment of the Rotator Cuffs Tears were the following: age (1), gender (2), and the pending worker's compensation claims (2). For clarification:

- The common[14] *nonoperative* treatment options physicians primarily prescribe include Closed Reduction, Percutaneous Hydrotomy, and Immobilization and Icing. Non-surgical joint treatment covers treatment to the extent of moderate arthritis.

- The common[14] *operative* treatments commonly consulted for include the following: Arthroscopy, Invasive Incisions, etc.

Age

The demographic of age is associated, typically, with older specimens compared to young, premature joint excursions. Older patients tend to portray worse tendon qualities and outcomes. However, the surgical outcomes are not necessarily poor. Despite the obvious statistic that larger results of muscular damage, 78% of patients over the age of 70 continue to exhibit naturally healthy qualities after surgical enhancement of the muscles.

On study investigated the relationship patient age and operative repair (the demographic variable, essentially) was brought between 35 patients less than 65 years old, and 53 patients of age 65 or older[16] the gradient for a satisfactory patient was observed through his/her ability to actively abduct to 145 degrees and externally rotate to 55 degrees with no or mild discomfort. On occasion, it was discovered that in the younger patient group, 3% of patients were proven to be unsatisfactory, while 89% of the patients proved to be satisfactory. In comparison, the older age demographic performed with 77% patients, who proved to be satisfactory – revealing the age-induced variable for muscular conditions.

Gender

An average of 55 months after open rotator cuff repair and acromioplasty somewhat suggests that the female gender is a negative prognostic factor, meaning a slightly smaller chance for a more positive recovery, compared to the male representatives.

The study results below indicate, based on the relative sample size, that 96% of patients reported improvements in their level of pain, and 74% reported complete painless recovery[17]. With this background, the study inquired the relationship in age and outcomes after 65 years of age, indicating that women [age >65] have worse outcomes regarding their shoulder scales. However, the limitation in the age of the men's surgery at their retrospective time leads to an inconclusive comparison between genders, as no correlation is identified.

Table 3²

Authors	Sample Size	Follow-up	Findings	Level of Evidence
Romeo et al.	72	Average 54 months	Women had a negative, statistically significant relationship between age and shoulder soring scales, but age at the time of surgery was not related to any outcome variables for man. An associated bicep tear in female patients is a poor prognostic factor.	IV
Cofield et al.	105	Average 13.4 years	Men had less postoperative pain and greater postoperative abduction than women.	IV

Worker's Compensation

The Worker's Compensation, under these indications, is implemented when a medical condition arises due to a workplace accident or occupational disease, and the payment will be incurred by the workers' compensation insurers.

A retrospective cohort study was conducted to indicate the relation of the worker's compensation to the satisfaction of the surgical outcome[18]. 33 patients with complete rotator cuff tears were categorized into two groups, which were defined following a comprehensive nonoperative rotator cuff muscle program of strengthening exercises. The average patient follow-up for these two scientific groups were estimated to be between a range of 2.6-4.6 years. The dissatisfaction rates were shown in 14 of the 33 patients, 12 of which had opted for surgical treatment.

As a result, these individuals who'd displayed a lower appreciation marking for the nonoperative treatment (Group II) had a higher proportion of individuals that claimed disability benefits than the latter population studied. Those who have an insurance stake in their clinical procedure exhibited a schedule of significant sleep loss, along with a lack of patients' improved pain relief[1] (the ability to carry a 10-15 lb. suitcase, use the arm at the shoulder level, etc.).

Conclusion

This literature illustrates a scientific breakdown for the complex system of Rotator Cuff Muscles. Through carefully analyzing parameter models of the Rotator Cuff's architecture, following the detailed calculations of the fixed muscle tissue and operating ranges of motion, the supraspinatus, infraspinatus, teres minor, and subscapularis muscles of the shoulder compartment were determined.

However, this process of judgment had several limitations. The previously mentioned [10% buffered] formalin solution led to a shrinkage in the cadaver's length of tissue, implying the normalized fiber length and initial sarcomere number measurements were underestimated. The unit of contraction wasn't considered over a bony compartment of the joint, indicating a level of operational uncertainty with the findings.

Based on these sarcomere differential ties mentioned above, the muscle fibers of the supraspinatus and infraspinatus muscle fibers were approximately 20% shorter, which can be explained by the sarcomere length findings. The infraspinatus and supraspinatus were measured at 3.18μm and 3.23μm, respectively. In comparison with the optimal sarcomere length of 2.7μm, these measurements indicate a shorter muscle fiber, as the muscular force generated increases when 'compromised' by a shorted muscle length (an inverse relationship). Thereby, the PCSA concretely increases as well. This data suggests that the rotator cuff muscles, combined, produce the optimal force at 25° abduction and 20° lateral rotation. In consistency with their proposed role as stabilizing the glenohumeral head, the archi-

tectural arrangement of the rotator cuff muscles indicate they are designed for force rather than excursion. The modeled sarcomere length-joint angle, which exhibits a range from 4-5, shows that the Rotator Cuff muscles generate relatively large tensions over most joint angles.

Limitations

The secondary portion of this paper is extensively conclusive of the fact that more data is needed to be done to determine the importance between the fluctuating factors that help guide the Rotator Cuff tear treatment. The lack of clinical trials regarding the usage of nonsteroidal anti-inflammatory drugs, physical therapy, and corticosteroids, along with the sole basis of the physicians' personal experience to treatment decisions for symptomatic full-thickness cuff tears limit the scope of investigation.

Although the processed data configures a relative relationship between factors such as the age demographic and gender, the influence of multiple variables of treatment decision fogs the ultimate outcome. The different clinical presentations, surgical techniques, and available nonoperative and operative treatment options in the treatment of Rotator Cuff Muscles reflect a randomized control. This displays multiple flaws in a trial that may not be feasible or ethical.

The treatment scenarios presented only concerned patients with complete Rotator Cuff tears. The treatment scenarios for injuries such as partial tears and subacromial bursitis[1] (inflammation of the bursa which separates the superior surface of the supraspinatus tendon from the coracoacromial ligament). The lack of Rotator Cuff disease is equally limiting. The takeaway from such superficial understanding, case scenarios, is that nonoperative treatment regarding *full* Rotator Cuff tears consist of anti-inflammatory medicine (ibuprofen, etc.) and physical therapy for a timeline of 6 weeks (about 1 and a half months) and 3 months – patients' age, activity level, vocation are minimal factors that can truly affect the outcome [per the studies].

Acknowledgement

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