Suture Technique Influences the Biomechanical Integrity of Pectoralis Major Repairs

By

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THESIS
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Summary

A biomechanical study was conducted to compare repair techniques on the pectoralis major tendon. Furthermore, the biomechanical performance of repaired pectoralis major tendons are compared to intact native tissue.

Forty fresh-frozen cadaver shoulder specimens were dissected and randomized to four repair groups. All specimens were repaired with endosteal Pec buttons (Arthrex Inc., Naples, Florida). Control, the baseline repair, consisted of a Mason-Allen simple stitch double loaded with No. 2 fiberwire (Arthrex Inc., Naples, Florida). The triple repair group consisted of a Mason-Allen stitch triple loaded with No.2 fiberwire. The configuration repair group uses a modified Krackow complex stitch double loaded with No. 2 fiberwire. The final repair group used the modified Krackow stitch technique double loaded with No. 5 fiberwire (Arthrex Inc., Naples, Florida) and fibertape (Arthrex Inc., Naples, Florida). Specimens underwent cyclic loading, at 90N/s from 10-125N for 150 cycles, followed by pull to failure testing at 1mm/s

While cyclic loading had no significant difference, pull-to-failure testing indicated the tape group withstood a significantly greater maximum load than the groups repaired with Mason-Allen stitches. Furthermore, there were significant differences for both cyclic and pull to failure tests between the intact native tissue and all four repair techniques.

Although repaired tendons are found biomechanically inferior to native intact tissue, suture technique can improve the biomechanical performance of pectoralis major repairs by preventing suture pull-out from tendon at lower loads. As loads increase, suture breakage may occur unless robust suture such as polyethylene tape and No. 5 polyblend are used (tape group).
**Section 1: Introduction**
Pectoralis major muscle is a strong shoulder stabilizer with the primary functions of flexion, adduction and internal rotation. This pennate muscle is attached to the clavicle and sternum with the insertion site on the bicipital groove of the humerus (Figure 1.1). The belly of this large muscle forms the anterior wall and the fold of the axila profile. The morphological differences within the regions of the pectoralis major indicate the larger sternocostal portion is at higher risk for ruptures due mechanical instability at extension\(^3,5,12,13\). As seen in figure 1.1 and 1.2, the inferior sternal portion of the pectoralis major muscle is inserted to the humerus at a higher angle than the clavicle portion. According to the three dimensional model created by Fung et al, the clavicle region is a uniform segment, while the sternum region can be divided into several segments based on fascial planes\(^5\). Figure 1.2 demonstrates the segment delineation as defined by Fung et al. Currently, there are conflicting theories to whether tendon fibers twist upon themselves to the insertion site or if the tendon fibers are arranged in layers. While Wolfe et al claim the pectoralis major is a trilaminar muscle, many studies have concluded the tendon fibers are bilaminar with anterior and posterior layers\(^23\).

![Figure 1.1 Pectoralis Major Anatomy. Clavicle and Sternum portion highlighted](stlhealthandwellness.com)
Tears along the pectoralis major tendon is a traumatic injury, in which most cases require surgical intervention. Individuals involved in weight lifting, wrestling, gymnastics, and heavy labored tasks are at an increased risk to rupture the pectoralis major tendon\textsuperscript{1,2,6,8,12,13}. In particular, the eccentric contraction required during bench press activity has been reported in many cases of pectoralis major tears. Studies have indicated this injury is male dominant within the age range of 18-45 years old\textsuperscript{1,4}. The patient’s range of motion and strength is significantly reduced after injury occurs. Deformity of the chest profile is visible with comparison of both sides of the patient. Ecchymosis is another indication of a pectoralis major injury, which can be visible...
occur along the chest and shoulder as seen in figure 1.3. A physical examination and MRI scan are used to assess the severity of the injury (Figure 1.4). There are three primary locations a tear in the pectoralis major can occur; a bony avulsion along the humeral insertion, tendon separation within the musculotendinous junction or insertion and tear along the muscle belly\(^4\). With the majority of patients experiencing tears along tendinous and musculotendinous regions, injury classifications for the pectoralis major are utilized for optimal diagnosis (Figure 1.5).

Figure 1.3. Signs of torn pectoralis major: A) Bruising B) Deformity within chest profile (http://stlhealthandwellness.com/pectoralis-tendon-tears/)
Figure 1.4. MRI Scans A) Complete tendon tear. B) High Grade Partial Tear C) Low Grade Partial Tear. (Modified from Zvijac et al, 2006)

Figure 1.5. Standard Pectoralis Tear classifications (El Maraghy et al, 2012)
Current Surgical Repair Techniques

Surgical repair allows for optimal patient outcome as strength and physical appearance is restored. Most individuals with pectoralis major tears are athletes that require increased physical strength. Case reports have shown majority of patients return to 80% activity level post repair\textsuperscript{1, 4, 10, 11, 13}. For acute tears, the tendon must be pulled back to the humerus and anchored to the bone. Common surgical options for pectoralis major tendon tears includes trans osseous techniques, suture anchors, and cortical bone buttons. Another important aspect of surgical repairs for pectoralis major tendons is the stitch technique. Stitch techniques vary with the amount of suture that grasps the tendon, securement method and overall complexity of the stitch method. Two common stitch techniques include the mason-allen and the krackow configurations. The mason-allen is classified as a standard simple stitch, while the krackow stitch uses a complex running, locking method within the tendon.

Prior Pectoralis Major Repair Studies

Previously at Rush University Medical Center, Sherman et al investigated the biomechanical properties of three tendon repair techniques for the pectoralis major. The three experimental repair groups included trans osseous, suture anchors and endosteal pec button, utilizing the simple mason-allen stitch. This study also included analysis of native intact pectoralis in order to assess restoration of normal properties after repair. All four groups underwent cyclic loading and pull to failure tests. Sherman found no significant biomechanical differences among the three repair groups, while the intact native tissue showed a superior biomechanical profile compared to all the repair techniques\textsuperscript{18}. Interestingly, a similar study by Hart et al also found no differences between trans osseous sutures and suture anchors repair technique with the complex krackow
stich configuration. Reported failure loads from Hart were significantly higher than values from Sherman indicating stitch technique may be a factor. A third study by Rabuck et al investigated the repair strengths of tran osseous, cortical buttons and suture anchors on pectoralis major tendons with the krackow stitch. This study concluded based on failure load that tran osseous tendon repair was the strongest technique (Figure 1.6). The conflicting data between these studies prompted our research team at Rush University to evaluate repair strength by suture number, stitch configuration and material. With the motivation to determine the optimal repair technique for pectoralis major tendon tears a follow-up study was developed. Standardized tissue handling, testing methods and data analysis used at Rush University Medical Center allows for direct comparison between studies.

![Figure 1.6 Stitch configurations for related biomechanical studies. A) Sherman et al-Modified Mason Allen B) Hart et al- Modified Krackow C) Rabuck et al- modified Krackow](image)

Mechanical Properties of Tendon

Tendon is a band of dense fibrous connective tissue that connects muscle and bone. The primary function of tendon is to transmit force exerted from the muscle. Tendon is composed of an extracellular matrix containing 70-80% type I collagen, 1-2% elastin along with glycoproteins
and proteoglycans dispersed throughout the structure\(^9\). The hierarchical arrangement of fibrils, fibers and fascicles is designed to withstand high tensile force (Figure 1.7). The fibril is the smallest unit of the tendon structure with a diameter ranging from 10-500nm. Fibers, the next structural component of a tendon, are composed of collagen fibrils with a diameter size of 1-20µm. Fiber bundles, with diameters of 20-200µm, form fascicles and bundles of fascicles used for vascular, lymphatic, and nerve supply to the tendon\(^{21,22}\).

Tendon exhibits nonlinear mechanical properties due to the hierarchical structure formed by the collagen fibrils. Fibrils consist of many uncrimped collagen fibers straighten during the first few periods of tissue stretch, called the toe region. As the tensile force continues to increase more tendon fibers are recruited to form the linear region of the stress versus strain curve. The collagen fibers are stretched 4% within the linear region without any permanent damage to the tissue. Plastic deformation begins with microscopic tearing when tendons are stretched over 4%. Failure occurs once the tendon fibers stretch 8-10% , in which there is permanent damage to the tissue\(^{21,22}\)(Figure 1.8).
Tendon is also a viscoelastic material, in which the force-displacement relationship for this tissue is dependent on the rate of stretch. Viscoelastic behavior can be measured by creep, stress relaxation, and hysteresis of the material. Creep refers to the time-varying deformation that occurs to a material under a constant load, while stress relaxation is defined as the gradual reduction in stress on a material while held at a constant deformation (Figure 1.9).

A. [Diagram of creep]

B. [Diagram of stress relaxation]

Figure 1.9. Viscoelastic properties. A) Creep B) Stress Relaxation

Figure 1.8 Stress-strain relationship of tendon
The third characteristic of viscoelasticity is hysteresis of a material. Hysteresis is measured from a load vs. displacement plot during loading and a subsequent unloading phase. Under cyclic loading, the strain energy dissipated from the tendon recoil can be evaluated. As in figure 1.10, after recurring cyclic loading the curves gradually begin to shift to a constant stress-strain curve.

Figure 1.10. Viscoelastic property: hysteresis

To evaluate mechanical properties of native tendon and repaired tendons in a laboratory setting, crosshead displacement from the MTS system as well as strain measured from optical system is optimal. Mechanical response of repaired tendons is assessed as a construct rather than a pure tendinous tissue segment. The repair construct requires extensive observation with all components of the unit: bone, tendon, musculotendinous junction and repair components (i.e. suture, cortical buttons). Although, micro motion cannot be analyzed, the repair construct as well as regional properties can be evaluated. Crosshead displacement provides information regarding the entire bone-tendon-muscle unit tested. Local strain and loading patterns based on
anatomy or repair site is a useful for evaluating repair techniques on tissue. Along with mechanical parameters, mode of failure demonstrates the construct component that compromises the biomechanical integrity.

Objective

Pectoralis major tendon repairs restore function for patients. This injury calls for robust techniques to fix a large and powerful tendon. Ultimately, this study is designed to improve patient care by evaluating mechanical properties of the pectoralis major tendon based on repair techniques. Material type, suture configuration as well as the number of sutures placed at repair site will be assessed through repair groups. The goal for this study is to determine which combination of surgical strategies will provide the greatest mechanical stability.

Specific Aim #1: Compare the biomechanical properties of pectoralis major tendon repair groups to those of native (intact) tissue.

Hypothesis 1: The biomechanical profiles of repaired pectoralis major tendons shows no difference from the intact native tissue

Specific Aim #2: Compare the biomechanical characteristics of repaired pectoralis major tendon based on suture number along repair site, stitch technique or material

Hypothesis 2: The suture technique of repaired pectoralis major tendons shows no influence on the biomechanical performance.
Section 2: Methods

Specimen Preparation

Table 2.1 Summary of Demographics of Cadaveric Shoulders

<table>
<thead>
<tr>
<th>Study Group</th>
<th>Age</th>
<th>Sex, n</th>
<th>Shoulder Side, n</th>
<th>Body Mass Index</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± SD, y</td>
<td>Male</td>
<td>Female</td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>56.2 ± 15.5</td>
<td>4</td>
<td>6</td>
<td>25.9 ± 9.0</td>
</tr>
<tr>
<td>Triple</td>
<td>53.5 ± 15.8</td>
<td>5</td>
<td>5</td>
<td>23.7 ± 6.8</td>
</tr>
<tr>
<td>Configuration</td>
<td>54.8 ± 13.0</td>
<td>5</td>
<td>5</td>
<td>23.1 ± 5.0</td>
</tr>
<tr>
<td>Tape</td>
<td>55.6 ± 16.6</td>
<td>5</td>
<td>5</td>
<td>24.1 ± 7.2</td>
</tr>
<tr>
<td>Intacta</td>
<td>77.8 ± 11.3</td>
<td>4</td>
<td>2</td>
<td>-</td>
</tr>
</tbody>
</table>

α- Data collect from Sherman et al study

Forty fresh-frozen, human cadaveric shoulders from thirty subjects were distributed into 4 groups of 10 specimens each, based on age, sex, and BMI (Table 1.1). A given contralateral pair of specimens was not assigned to the same repair group. A pre-study power analysis revealed that a sample size of 7 specimens per group were required to detect a mean difference of 100N in maximum load, with a 50N standard deviation, for \( p < 0.05 \) and a statistical power of 90%. We felt a difference of 100N would represent a clinically relevant difference in biomechanical strength. The specimens were thawed prior to dissection, repair, and testing. The pectoralis major muscle was identified through a deltopectoral approach and dissected free of skin and any underlying soft tissues. All other muscles of the humerus were excised (Figure 2.1).
Repair Techniques

A.  

B.  

Figure 2.1, Specimen preparation. Right humerus with pectoralis major attached after dissection. Tendon side (A) & Muscle side (B)

The insertion of the pectoralis major tendon was marked on the humerus, and the length and width of the tendon at its insertion, defined as tendon footprint, was measured with a digital caliper. The tendon length, defined as the distance from the insertion to the musculotendinous junction, was measured. The tendon was then excised from its bony insertion and repaired to the bone with one of four suture repair techniques: “control”, “triple”, “configuration”, and “tape” (Figure 2.2). The effective tendon length, defined as the exposed tendon following the reattachment to the bone, was measured.
All repair techniques utilized three Pec Buttons (Arthrex Inc., Naples Florida). The Pec Button is a 2.6 x 10.9mm titanium suture button. It has a 45° angle on each end of the button, so that it rotates upon striking the far cortex of the bone, allowing endosteal engagement upon tensioning.

A 3.2mm drill bit was used to create three unicortical holes at the pectoralis footprint. One hole each was placed 5mm from the proximal and distal edges of the footprint, and the third hole was

Figure 2.2. Standardize specimen preparation for repair: A) Drill holes measured and marked along the insertion site. B) Footprint is measured and marked. C) Three holes are drilled into the humerus. D) Pec buttons loaded with fiberwire and/or fibertape is inserted.
placed equidistant between the other two. The Pec Buttons were loaded with the appropriate suture, inserted into the medullary canal, and toggled to engage the endosteal cortex.

In the “tape” group, in order to accommodate the larger caliber of the 2mm width polyethylene tape (Fibertape; Arthrex Inc., Naples Florida) and No. 5 polyblend suture (Fiberwire; Arthrex Inc., Naples Florida), slightly wider Pec Buttons were used. These measured 3.2 x 10.9mm, and were inserted after drilling with a 4.0mm drill bit.

![Figure 2.3. Materials used for pectoralis repairs](image)

Tendon repair for the control group was performed using the technique described by Sherman et al\(^18\). The Pec Buttons were double-loaded with No. 2 polyblend suture (Fiberwire; Arthrex Inc., Naples Florida). After insertion, one arm of each suture was passed through the tendon in a modified Mason-Allen stitch configuration. This led to a total of six sutures crossing the repair site. The free limb of the suture was tensioned to reduce the tendon to the bone, and the sutures were tied using standard alternating half-hitch knots.
For the triple technique, the number of sutures crossing the repair site was increased. The Pec Buttons were triple-loaded with the same No. 2 polyblend suture, and the same modified Mason-Allen stitch configuration was used. This led to a total of nine sutures crossing the repair site\textsuperscript{18}.

The configuration technique consisted of a different stitch configuration within the tendon. First, the Pec Buttons were double-loaded with the same No. 2 polyblend, and one suture from each button was passed in a running, locking Krackow stitch. The second suture was then passed in
an overlying Bunnell stitch. A total of six sutures crossed the repair site. The free limbs of the
suture were tensioned, and the sutures were again tied with alternating half-hitches. This
configuration is similar to that described by Hart et al.\textsuperscript{7}

Figure 2.6. Configuration Group: Locking Krackow stitch w/ overlapping Bunnell. Double-
loaded original pec buttons with #2 fiberwire

Finally, for the tape group, an alternative suture material was used in addition to a slightly wider
modified Pec Button, as described above. The button was double-loaded with 2mm width
polyethylene tape and No. 5 polyblend suture. Overall, the same suture technique as the
configuration was used. The tape was used to pass the running, locking Krackow stitch, and the
No. 5 polyblend was used for the overlying Bunnell stitch. Again a total of six sutures crossed
the repair site\textsuperscript{7}.
Figure 2.7. Fiber Tape Group: Locking Krackow stitch w/ overlapping Bunnell. Double-loaded modified pec buttons w/ Fibertape and #5 Fiberwire.

Figure 2.8 Repair layout for all four repair groups. Illustrated by Kristen W. Marzejon, CMI of MedArtDesign
Biomechanical Testing

After surgical repair of the pectoralis major, the humerus was cut transversely 4 inches distal to the insertion site. The humerus was potted in a 3 inch long by 2 inch diameter polyvinyl chloride (PVC) pipe using acrylic cement (Isocryl, Lang Dental Manufacturing Co., Inc, Wheeling, Illinois). The repaired tendon cross-sectional area, as well as the muscle belly width were measured with a digital caliper. The pectoralis major tendon was secured using a custom cryogenic clamp. The musculotendinous junction was gripped within the clamp to prevent muscle slippage during testing. Dry ice was applied for 10 minutes prior to cyclic and failure tests to freeze the muscle belly. The tendon and musculotendinous junction were maintained at approximately 19ºC using a warm saline solution, while the muscle belly was maintained at -4ºC as verified by an infrared thermometer (Extech Instruments Corporation, Waltham, MA). The tendon fibers were aligned along the direction of the applied load. Gauge length, defined as the length from the bone-tendon interface to cryogenic clamp for each specimen, was measured for each specimen.

Once the pectoralis major tendon was gripped inside the clamp, two rows of three 2.5mm markers were placed on the humeral shaft and above the repair site, respectively. The placement of optical markers enabled differences in displacement to be observed with regard to the proximal, medial and distal portions relative to the humeral head for each specimen. Throughout tensile testing, digital video was acquired at 40Hz using a 2.8 Megapixel camera (Imperx, Boca Raton, Florda). Initial optical segment length was based on specimen construct and anatomy of the exposed tendon. Three markers were placed 5mm lateral to the insertion site; two markers were attached to either end and the third marker was placed in the center. Three additional markers were placed along the exposed tendon area, superior to the repair construct, creating
optical segments. Marker placement and initial segment lengths were measured, prior to testing in a taut, using a digital caliper (Figure 2.9).

![Figure 2.9 2.5mm optical marker placement](image)

The specimen was then secured to a MTS Insight 5 Materials Testing System (MTS Inc, Eden Prairie, Minnesota) using custom designed jigs for the potted distal humerus and the humeral head. The predominant tendon fibers were maintained in the direction of the applied load with the humeral shaft positioned directly inferior to the pectoralis muscle and in a neutral rotation with respect to the repair construct (Figure 2.10). To aid with optical tracking, additional lamps were used to optimize tendon & tracker visibility. Following the procedure described by Sherman et al\textsuperscript{18}, cyclic and pull-to-failure tests were performed for each specimen. The pectoralis major tendon was pre-loaded at 10N for 2 minutes, and then tested from 10N-125N for 150 cycles at 90N/s. After cyclic testing, each specimen was pulled to failure at a rate of 1mm/s. Load, time, and actuator displacement data were acquired synchronously with the optical marker data using MTS TestWorks 4 software and Digital Motion Analysis Software (DMAS, Spica}
Technology Corporation, Maui, HI), respectively. Construct failure was visually classified as occurring at the musculotendinous junction, tendon, suture, or bone.

A. 

B. 

Figure 2.10. A) Testing setup with camera and MTS systems B) Specimen set up with custom made fixtures and cyrogenic clamp attachment.

Data Analysis

From the cyclic test, 4 primary parameters were quantified: (1) initial excursion, defined as the increase in segment length from the preloaded state to the peak of the first cycle; (2) cyclic creep, defined as the relative increase in crosshead extension from the peak load of the first five cycles to the peak load of the last five cycles of testing; (3) cyclic elongation, defined as the relative increase in segment length from the peak load of the first five cycles to the peak load of the last five cycles and (4) mean secant stiffness of the first five as well as last 5 cycles, with secant stiffness defined as the slope of the line joining minimum and maximum points of the loading phase of the force-deformation curve. From the pull-to-failure test, three parameters were quantified: (1) maximum load, (2) extension at maximum load, defined as crosshead displacement at maximum load, and (3) linear stiffness, calculated as the maximum slope of the
load displacement curve spanning 40% of the data points collected between initiation of the failure test and the maximum load.

Optical data were analyzed using the Tracker and Reporter programs available in the DMAS camera software (Imperx, Boca Raton, Florda). Details regarding calibration of the camera system can be found in the Appendix. Once a tested specimen is recorded through the capture program, a .DDF media file and spatial model text file is created. The total marker number \( m=6 \) and segments assignment (e.g., 1S= 1m: 2m in Figure 2.11) were defined within a spatial model for each cyclic and failure testing videos (Figure 2.11). Optical markers are labeled with the tracker program by selecting the optimal centroid threshold level. Each marker is tracked in units of mm for both the X and Y coordinates. The segment length \( R \) is tracked by using the shortest distance between a pair of markers \( \sqrt{(\Delta X^2 + \Delta Y^2)} = R \). The reporter program gathers the defined displacements for each tracked media file in .CSV format. Raw data is then analyzed using excel. Subsequently, from these optical data, relative cyclic elongation, absolute cyclic elongation, relative extension at maximum load), and absolute extension at maximum load were quantified. Cyclic elongation data was calculated by averaging the segment lengths during first and last five cycles. Extension at maximum load was determined as the segment length increase from the first frame to the frame when peak load occurred. All relative optical data was normalized to the initial cyclic segment length.
Figure 2.11. Schematic model of marker and segment assignments.

Anatomical, mechanical and optical data were analyzed for all four repair groups using a one-way analysis of variance (ANOVA). When significant differences were noted among repair groups, a Tukey post-hoc test was used for multiple pairwise comparisons to detect significant differences due to repair technique. A two-tailed, paired t-test was employed to compare pre and post-repair tendon lengths within each repair group. The threshold for statistical significance was set at \( p < 0.05 \) for all parameters. All statistical analyses were conducted using GraphPad Prism 5®.
Section 3: Results

Among the forty specimens included in this study, two specimens (triple loaded and fiberwire configuration group) failed at the musculotendinous junction during cyclic testing and were therefore excluded from the data analysis as neither sample completed both cyclic and failure tests.

Anatomical Data

Age, body mass index (BMI) and cross sectional area (CSA) of the pectoralis major tendon between the four groups showed no significant difference (p<0.05). Maximum load when compared to age, BMI, and CSA had no statistical correlation for this study (Figure 3.1). Tendon length and footprint area between all four groups were not significantly different. There was a difference detected between gauge length of the triple group (20.5 ± 4.9 mm) and the tape group (29.4 ± 5.9 mm). This difference in length is due to the additional fiberwire and fibertape used along the pectoralis major tendon (Figure 2.8). In order to maintain the integrity of the repair construct, specimens in configuration and tape repair groups were both gripped with a
longer gage length. In addition, effective tendon length was significantly reduced post repair for all four groups. This is indicative of the excised tendon anchored back onto the bone.

<table>
<thead>
<tr>
<th>Repair Type</th>
<th>Muscle Length (mm)</th>
<th>Muscle Width (mm)</th>
<th>Foot print (mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>139.6 ± 22.4</td>
<td>5.0 ± 1.0</td>
<td>53.7 ± 11.3</td>
</tr>
<tr>
<td>Triple</td>
<td>153.8 ± 18.4</td>
<td>4.6 ± 1.8</td>
<td>54.7 ± 6.2</td>
</tr>
<tr>
<td>Configuration</td>
<td>170.9 ± 32.3</td>
<td>4.9 ± 1.8</td>
<td>56.9 ± 5.3</td>
</tr>
<tr>
<td>Tape</td>
<td>142.7 ± 25.9</td>
<td>5.29 ± 1.8</td>
<td>58.9 ± 13.0</td>
</tr>
</tbody>
</table>

Table 3.2 Anatomical Tendon Measurements

<table>
<thead>
<tr>
<th>Repair Type</th>
<th>Pre Repair Tendon Measurements</th>
<th>Post Repair Tendon Measurements (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Length (mm)</td>
<td>CSA(mm²)</td>
</tr>
<tr>
<td>Control</td>
<td>55.9 ± 7.5</td>
<td>73.2 ± 27.36</td>
</tr>
<tr>
<td>Triple</td>
<td>59.6 ± 7.6</td>
<td>73.77 ± 25.65</td>
</tr>
<tr>
<td>Configuration</td>
<td>60.2 ± 7.0</td>
<td>71.22 ± 31.14</td>
</tr>
<tr>
<td>Tape</td>
<td>58.4 ± 11.9</td>
<td>69.63 ± 26.85</td>
</tr>
<tr>
<td>Intact*</td>
<td>64.4 ± 5.6</td>
<td>-</td>
</tr>
</tbody>
</table>

*α- Data collect from Sherman et al study\(^{18}\)

\(^*\)- significant difference between tape and triple groups

Mechanical Data

Cyclic loading the pectoralis major tendon from 10N-125N for 150 cycles at 90N/s did not reveal any significant differences between the repair groups. As stated before, two specimens (one from the triple group and one from the configuration group) failed at the musculotendinous junction during cyclic testing and are not included in the data analysis provided.

The initial excursion for the repair groups, configuration (5.0 ± 2.1mm) and tape (5.4 ± 3.4mm), composed with running stiches along the tendon length showed no difference during cyclic loading when compared to the control (4.2 ± 2.4mm) and triple group (3.8 ± 1.0mm). Relative cyclic elongation for the complex repair groups also had no significant difference from the basic repair techniques. Secant stiffness for all four groups remained consistent throughout cyclic
loading. Interestingly, the tape repair group exhibited the largest change in secant stiffness from the initial five with $43.1 \pm 10.8 \text{ N/mm}$ to the last five cycles with $47.3 \pm 11.2 \text{mm}$.

The native intact tissue from Sherman et al\textsuperscript{18} showed a significant difference for all cyclic parameters included in the prior study when compared to the four repair techniques. Tissue displacement parameters, initial excursion, relative cyclic creep, and relative cyclic elongation, were all lower for the intact native tissue ($1.0 \pm .5, 2.2 \pm 1.0\%$, and $1.5\pm1.5\%$). Secant stiffness remained consistently higher than all the repair techniques during cyclic loading for the native intact tissue (initial phase: $1.0 \pm .5$ final phase: $74.8 \pm1.6\text{N/mm}$)

<table>
<thead>
<tr>
<th>Table 3.3. Summary of Cyclic Data (Mean ±SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
</tr>
<tr>
<td>-------------------------------</td>
</tr>
<tr>
<td>Initial excursion, mm</td>
</tr>
<tr>
<td>Initial excursion, %</td>
</tr>
<tr>
<td>Relative cyclic creep, %</td>
</tr>
<tr>
<td>Relative cyclic elongation, %</td>
</tr>
<tr>
<td>First five cyclic Secant stiffness, N/mm</td>
</tr>
<tr>
<td>Last five cyclic Secant Stiffness, N/mm</td>
</tr>
</tbody>
</table>

$^a$- Data collect from Sherman et al study\textsuperscript{18}  
$^{*}$- Intact native tissue is significantly different than all other repairs

Pull to failure test at 1mm/s for all four pectoral major tendon repair groups showed significant differences for the fibertape group for all measured parameters. The average maximum load for the tape group was reported at 726N, while configuration, triple and control were much lower at
values of 509.9 N, 400.2N and 330.2N, respectively. The intact native tissue was reported with a significant higher maximum failure load at 1454.8 N compared to all four repair groups.

Control, triple and tape repair groups had majority of failures occurring within the tendon-suture interface. Specifically, sutures cutting through the tendon at the maximum load during the failure test. Interestingly, the configuration group majority of specimen failures due to suture breaking at the maximum load. The maximum load sustained by the tendon-repair construct increased with the added running stitch and material strength included for both the configuration and tape repair techniques. The extension at max load increased with the complexity of the repair technique. The tape repair group reported an average tendon extension at maximum load to be 26.5mm, with configuration at 18.9 mm, triple at 13.5mm and 10.3mm. The extension at maximum load for the intact native tissue was reported significantly lower than all repair techniques (8.2±4.8%) Finally, linear stiffness for the fibertape group was significant lower at an average of 55.4 N/mm than all other repair techniques, while the intact native tissue was reported significantly higher at 221.0 ±111.7N/mm.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Control (n=10)</th>
<th>Triple (n=9)</th>
<th>Configuration (n=9)</th>
<th>Tape (n=10)</th>
<th>Intact* (n=6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Load, N</td>
<td>330.2 ± 64</td>
<td>400.2 ± 105.6</td>
<td>509.9 ± 205.8</td>
<td>726.0 ± 84.7**</td>
<td>1454.8 ±795.7***</td>
</tr>
<tr>
<td>Extension at Max Load, mm</td>
<td>10.3 ± 3.9</td>
<td>13.5 ± 6.2</td>
<td>18.9 ± 8.1</td>
<td>26.5 ± 10.5**</td>
<td>10.6 ±4.1*</td>
</tr>
<tr>
<td>Relative Extension at Max Load, %</td>
<td>48.5 ± 25.7</td>
<td>69.4 ±39.6</td>
<td>79.5 ± 38.2</td>
<td>99.1 ± 38.0*</td>
<td>8.2±4.8 a***</td>
</tr>
<tr>
<td>Linear Stiffness, N/mm</td>
<td>91.4 ± 24.4</td>
<td>88.5 ± 15.49</td>
<td>85.6± 25.55</td>
<td>55.4 ± 14.9***</td>
<td>221.0 ±111.7 a***</td>
</tr>
</tbody>
</table>

α- Data collect from Sherman et al study
* - tape group is significantly different than control
**- tape group is significantly different than control and triple
***- tape group is significantly different than all other repair groups
α*- native intact tissue is significantly different than the tape group
α***- Native intact tissue is significantly different than all other groups
Optical Data

Thirty specimens had available optical data analyzed for regional elongation during cyclic testing, while thirty two specimens were successful recorded during failure testing. The loss of data was attributed to technical errors during the recording process. (Cyclic optics- control: n= 7, triple: n= 6, configuration: n= 8, Tape: n= 9; Pull to failure optics- control: n= 9, triple: n= 7, configuration: n= 8, tape: n=8).

Specimen samples with successful optical videos were tracked and analyzed for cyclic and failure tests. Initially, regional markers were placed proximal, medial and distal relative to the humeral head to evaluate any local changes in tendon elongation. Raw data from segment movement for each column was averaged due to insignificant elongation differences between
proximal, medial, and distal marker placement (figure 3.3). The reported data for optical tracking therefore represents the average elongation of the three vertical segments of markers (average of (1S, 2S, 3S).

Relative and absolute elongation were calculated for both cyclic and failure optical data. Both elongation parameters were included as a means to address clinical relevance. From cyclic testing, there were no significant differences between the repair groups in regards to relative elongation. Absolute elongation during cyclic testing did show a significant difference in optical data for the tape group (3.1 ± 1.5mm) compared to the control group (1.7 ± 0.8mm). Optical data from the failure test indicated a significant difference in relative elongation for the tape repair group (91.1 ± 31.9 %) and the control repair group (41.9 ± 16.2%). Lastly, absolute elongation data for optical tracking indicated a significant increase in the tape group (21.2 ± 6.9 mm) when compared with the control group (8.1± 3.4 mm) and the triple group (8.5 ± 3.5).

Figure 3.3 Optical Segment Tracking A) Pull to failure B) Cyclic loading
# Table 3.6 Optical Marker Data

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Triple</th>
<th>Configuration</th>
<th>Tape</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cyclic</strong></td>
<td>n=7</td>
<td>n=6</td>
<td>n=8</td>
<td>n=9</td>
</tr>
<tr>
<td>Relative Elongation, %</td>
<td>10.2 ± 4.7</td>
<td>13.0 ± 6.6</td>
<td>10.5 ± 3.7</td>
<td>14.2 ± 8.7</td>
</tr>
<tr>
<td>Absolute Elongation, mm</td>
<td>1.7 ± .8</td>
<td>1.8 ± .5</td>
<td>2.1 ± .7</td>
<td>3.1 ± 1.5*</td>
</tr>
<tr>
<td><strong>Failure</strong></td>
<td>n=9</td>
<td>n=7</td>
<td>n=8</td>
<td>n=8</td>
</tr>
<tr>
<td>Relative Elongation, %</td>
<td>41.9 ± 16.2</td>
<td>54.1 ± 24.5</td>
<td>75.4 ± 39.4</td>
<td>91.08 ± 31.9*</td>
</tr>
<tr>
<td>Absolute Elongation, mm</td>
<td>8.1 ± 3.4</td>
<td>8.5 ± 3.5</td>
<td>14.8 ± 6.4</td>
<td>21.2 ± 6.9**</td>
</tr>
</tbody>
</table>

*- significant difference between control and tape groups
**- significant difference between control and tape, and between triple and tape groups

![Figure 3.4](image-url) Relative optical Elongation A) Cyclic loading B) Pull to failure (no significant differences found in cyclic optics)
Section 4: Discussion

The present study demonstrates that variation in suture technique has a marked effect on the biomechanical integrity of pectoralis major repair constructs. Motivation to investigate repair techniques for pectoralis major tendon tears began as previous biomechanical studies focused on methods of bony fixation, with few differences among the fixation techniques. Sherman et al noted no biomechanical differences between trans osseous, suture anchor, and button fixation\textsuperscript{18}. Hart et al noted similar findings comparing trans osseous and suture anchors\textsuperscript{7}. Rabuck demonstrated a significantly lower load-to-failure with suture anchors compared to trans osseous repairs, but found no difference between trans osseous and cortical buttons\textsuperscript{15}\textsuperscript{,18}. The mode of failure of specimens in these studies varied from bone, suture and tendon. Noteworthy was that studies using Mason-Allen stitches have demonstrated overall lower ultimate failure loads (290N-360N) than those in which running, locking stitches were used (380N-620N)\textsuperscript{7,15,18}. The variation between these studies indicates suture placement appears to be the greatest factor to restore the damaged tendon. The need for a follow up study is highlighted as no studies exist that examine the biomechanical effect of suture techniques in pectoralis major repair.

Recall, the first specific aim for this study was to compare the biomechanical properties of the pectorals major tendon repair groups to those of native (intact) tissue. Following the same preparation and testing protocol performed in Sherman study\textsuperscript{18}, native tissue can be directly compared to the repaired tendons completed in this current study. The intact native tissue reported from Sherman et al\textsuperscript{18} indicated a significant difference in cyclic loading compared to all the repaired technique groups for all parameters. Furthermore, during pull to failure testing the intact tissue showed a significant difference from the repaired groups, for all parameters.
Thus, we can reject our hypothesis as there is significant evidence that indicates intact pectoralis tendon has a superior biomechanical profile compared to repaired tendons.

The second specific aim for this study was to compare the biomechanical characteristics of repaired pectoralis major tendons based on suture number along repair site, stitch technique or material. Under cyclic loading, no significant differences were found between the four repair groups. When loaded to failure significant differences between groups were reported. The fibertape repair group withstood significantly greater loads (726 N) than both the triple and control groups (400.2 N and 330.2 N). The control and triple repairs utilized the a modified Mason-Allen stitch with No. 2 polyblend suture, while the fibertape repair consisted of 2 mm polyethylene tape in a running, locked No. 5 polyblend suture. Extension at maximum load was significantly higher for the fibertape repair compared to the control and triple group, while the linear stiffness was significantly lower for the fibertape repair group. Findings from extension at maximum load and linear stiffness are consistent with the failure modes observed for each group.

To accurately address specific aim 2, the effect of the technique was evaluated. The suture number along the repair site is assessed by comparing the control and the triple repair groups (Figure 2.8). Both repair groups utilized the mason-allen, simple stitch, technique with the same suture material. The difference between the control and triple arises from the number of sutures loaded and subsequently pass through the tendon. The triple group consisted of nine sutures inserted along the repair site, while the control group had six. For both cyclic and pull to failure tests, these repair groups did not show any significant differences. From this data, we can
conclude suture number along the repair site did not influence the biomechanical integrity in this study.

To evaluate the effect of stitch configuration, the control and the configuration group are compared (Figure 2.8). The configuration repair group used No. 2 polyblend suture as the control, however, the running locked stitch configuration that was also used with the configuration group enabled the repair construct to maintain the tendon at higher loads as well. During cyclic loading these repairs showed no significant differences. The pull to failure test indicates a variation in mode of failure between the control and configuration repairs (Table 3.6). At relatively low forces (300-400N), the Mason-Allen constructs used for the control group failed from suture pull-out. The running, locking stitch pattern found in the configuration group prevents this early pull-out, but as the forces continue to increase (500N), the mode of failure shifts to suture rupture with the No. 2 polyblend suture failing.

The third repair technique, the effect of material, is evaluated by comparing the configuration and fibertape repair groups. Interestingly, the maximum load to cause failure for the configuration group was not significantly different than the fibertape repair group. Differences within the mode of failure for the configuration and fibertape groups indicate suture material influences the construct’s biomechanical integrity (Table 3.6). The configuration repair failed at the suture, while tendon (suture pull-out) failure occurred for fiber tape repairs. The fibertape group combines the running, locking configuration with a more robust 2mm tape and No. 5 polyblend suture, preventing suture breakage and allowing mean maximum load values in excess of 700N.
Indeed, with a mean maximum load of 726N, the tape construct demonstrates the greatest biomechanical strength of any pectoralis repair construct reported in the literature to date\textsuperscript{7,15,18}. Published biomechanical data appear to be consistent with our findings. Rabuck et al examined trans osseous and cortical button repairs with No. 2 Fiberwire in a Krackow stitch, and noted similar load-to-failure numbers (596N and 494N respectively), while reporting that suture breakage was the most common mode of failure\textsuperscript{15}. Hart et al also noted suture breakage as the most common mode of failure in suture anchor and trans osseous constructs with No. 2 Orthocord in the same Krackow/Bunnell configuration we tested\textsuperscript{7}. We believe that the intrinsic strength of the tape and No. 5 polyblend was greater than the No. 2, and therefore helped to eliminate suture breakage as a key mode of failure.

Optical analysis for both cyclic and failure tests surface deformation did not vary with anatomic region (proximal, medial, distal). Initial marker placement on the tendon arranged in segments was to identify regional loading patterns. Optical strain within the repair construct was similar between proximal, medial and distal areas. Once averaged, the optical marker elongation was calculated relative to the initial length at cyclic testing or as the absolute length increase during the pull to failure test. Relative cyclic elongation data did not reveal a significant difference between groups, however, absolute cyclic elongation showed a larger increase in fibertape repair group compared to the control. For the optical results from the failure test, relative cyclic elongation was significantly larger in the fibertape group than the control group. Absolute cyclic elongation indicated the fibertape group had a larger length increase compared to the simpler repairs found in control and triple groups. While both sets of parameters provide information
regarding the repair construct, relative elongation for cyclic and failure tests provides a clearer evaluation as the initial state is considered. Indeed, the fibertape group extends the tendon further than the simpler stitch groups, however, the anatomy and initial state of the repaired tendon vary between specimens. The fibertape repair group was gripped with a greater portion of exposed tendon in order to maintain the integrity of the repair construct, which increases the initial state. Optical data demonstrates the running stitches along the tendon along with the strength of the No 5. Polyblend sutures enables the tendon to have a larger elongation during testing.

Our choice of repair constructs was based on clinical applicability. As mentioned, previous studies have shown little difference between suture anchors, pec buttons, and trans osseous sutures\textsuperscript{18}. The Pec Button has a proposed advantage of shorter operative time and decreased surgical dissection, and in our hands, has been much faster than trans osseous repair. We chose to use modified Mason-Allen stitch for our control group to replicate the configuration we had previously evaluated\textsuperscript{18}. Varying the number of sutures crossing the repair site with the triple group appeared to have no effect. The Krackow/Bunnell construct was based on the construct described by Hart et al\textsuperscript{7}. This construct took more time to perform in the lab, and indeed, in small specimens, it could be challenging to fit all the suture limbs in the tendon. In vivo, however, pectoralis ruptures occur primarily in muscular individuals, and suture crowding is less of a concern. The overlying Bunnell stitch served as a way to standardize the number of sutures crossing the repair site. In the lab, it subjectively helped to “cinch” down the construct, although we do not know what the biomechanical contribution of the overlying Bunnell stitch is compared to the Krackow stitch alone. We did note while doing the repairs that the use of running stitches has a tendency to “bunch” up tendon tissue when fully tensioned. Further study is needed to
evaluate this. Additionally, we note that four Pec Buttons pulled out during load-to-failure testing. Again, this was a concern in smaller specimens, in which the medullary diameter is decreased and button rotation to appropriately engage the endosteal cortex becomes more difficult. Despite this, no specimen failed directly from button pull-out. Toggling the button to ensure endosteal engagement is essential.

The anatomy of the pectoralis tendon insertion also highlights the importance of suture management in pectoralis major repairs. The tendon is very broad and thin, in contrast to the rotator cuff, for example, with an insertion only approximately 6mm at its widest point\textsuperscript{18,23}. Therefore, there is little opportunity to use suture techniques to compress the tendon to the bony footprint, as we might see in a double-row rotator cuff repair\textsuperscript{20,23}. In addition, the thick diaphyseal bone at the insertion allows for good implant fixation. From this study, we hypothesize the strength of the pectoralis repair depends primarily on the friction created at the suture-tendon interface. This explains why a Krackow stitch configuration appears to better prevent suture pullout. Additionally, the increased surface area of the tape may help further increase this friction. Based on this anatomy, one would hypothesize that a tendon with similar insertional characteristics (i.e. latissimus dorsi) may show similar biomechanical repair results, although this has never been evaluated in the lab.

Overall, the strengths of our study include testing of repair constructs under both cyclic and load-to-failure protocols using biomechanical and optical data collection. We have evaluated suture constructs that are commonly used, described in the literature, and familiar to many orthopaedic surgeons. A post-hoc test power analysis revealed the current study has a statistical power of
60% based on the sample sizes used. We believe our study addressed our hypothesis, and provided clinically significant differences in biomechanical construct strength. However, as with all biomechanical studies, these results only reflect time zero, and do not account for any healing response, or potential repair impact on tendon vascularity. Although the tape construct demonstrates a biomechanical strength greater than any other in the literature, it still does not approach that of the native tendon 1450N\textsuperscript{18}. Additionally, the average age of our specimens (55 yrs), is likely older than the typical patient with a pectoralis major rupture, and tissue quality may be different.

In conclusion, we demonstrate that changes in suture configuration have a profound effect on repair strength in pectoralis major repair. First, we have demonstrated repaired tendons have inferior biomechanical profiles compared to intact native tissue. Athletes with a torn pectoralis major tendon are highly suggested to have surgical repair to restore strength and mobility. Under loads of 125N repair techniques do not differ, however, once the tendon reaches a large tensile force (270N and above) failure can occur. Use of a running, locking stitch configuration, such as a Krackow stitch, prevents suture pull-out at lower loads. Robust suture such as polyethylene tape or No.5 polyblend helps prevent suture breakage as loads increase. Repair techniques that utilize a longer, complex stitch configuration with stronger suture material is recommended for pectoralis major tendon tears.
Cited Literature


APPENDIX

Copyright Clearance

Figure 1.3 (Fung et al, 2009)
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Camera System Calibration

The field of view used for this current study is 100X50mm. The 2.8 megapixel camera (Imperx, Boca Raton, Florida) and digital motion analysis software (DMAS, Spica Technology Corporation, Maui, HI) were calibrated with the MTS machine used in this biomechanical study. An optical calibration block with black markers underwent standard cyclic, ramp-hold, and static protocols. Marker displacement and MTS crosshead displacement were compared. The optical measurements indicate an accuracy level of .05mm.
Ramp-Hold

![Marker 1](image1)
![Marker 2](image2)
![Marker 3](image3)
![Marker 4](image4)
![Marker 5](image5)

Static Hold

![Marker 1](image6)
![Marker 2](image7)
Digital Motion Analysis Software Protocol

Setting up Trigger with TestWorks (MTS)

- Open TestWorks and chose the method that you would like to work with
- Go to the DEFINE TAB → Configuration → Channels
  - Right Click in the channel list → Add New Hardware
- Add both Digital Output_1 and Analog Output_1 (Highlight and click OK)
- Click on Digital Output_1 and edit the formula so that it read the same as below
Click on Analog Output 1 and edit the formula so that it reads the same as below.

Go to the DEFINE TAB → TEST FLOW

Right click in the test flow where you want the trigger to begin (Right before movement begins)
  - Click Insert Before or After → Click on Digital Output → OK
  - Set Device to Digital Output 1 and turn to ON
  - Repeat input of Digital Output Command to turn trigger off once test is complete but set to OFF

Recording Video

Frame Size options on the calibration are identified below
  - 45x45 = 50mm Lens
  - 100x50 or 150x50 Frame Sizes = 25mm Lens
• Set up the camera as seen below

Open Sync (Wait for it to initialize – and then it will minimize; Click on it in the right hand corner of the screen to re-maximize)

Change the Settings as follows:

- All outputs set to 00
- Ref 00 is clicked with a frequency of 40Hz, Duty C. of 10, Trigger set to Input 00, and Trigger Mode set to continuous → Click SET
- In Ref 12-15 make sure they are ALL set to 40Hz, Duty C. of 10, Trigger set to Gen 00, and Trigger Mode set to continuous → Click SET
- Minimize Synch (DO NOT CLOSE)
- Open Calibration → File → Open → Click on the file type that you would like to use (based on Frame Size) → Click Open
  - Click on Live Video → Under Shutter click View ALL (You should see live feed from the camera; if not try to adjust lighting)
    - Right click on the picture → Click auto adjust video size
    - Make sure you can see the frame size that you want on the calibration frame (Get as close as possible to optimize video quality)
  - Hold Ctrl and click on the center of a crosshair to zoom in (and hold) → release to place the marker
    - Click on the 5 crosshairs starting with the lower left hand corner cross hair and move counterclockwise with the last (5th) marker as the central crosshair

- Once all the points are placed go to File → Save → Click OK
  - Click on Hide all shutters and turn off the live video
  - Close Calibration

- Open Capture → File → New → Click on the file type based on your previous calibration (frame size)
  - Click Preview → Under Shutter click VIEW ALL (You should see live feed from the camera)
    - Make sure all your markers are in view and have enough room to move (If not move MTS position)
  - When everything looks good and MTS is ready set Trigger to Input 00 and Trigger Mode to Start/Stop (Lower left hand corner of the module) → Click SET
    - Make sure frequency is 40Hz and Duty Cycle is 10%
  - Click Stop → Prepare → Record (Time should not start as it is waiting for the trigger)
Click Go in TestWorks (MTS) and Time should start
- Once the test is finished click Stop then File → Save (it will ask you for a file name) → SAVE
- If more than 5 markers or segments need to be tracked, find the spatial model file (.txt) that is created once the video is saved
  - Change Marker count
  - Add marker number and coordinate based on calibration file (x,y)
  - Change Segment count
  - Add segment number and coordinate based on markers (1m,2m)

Open Tracker-BETA → File → Open → Find the file that you want to analyze (Open the .DFF)
- Click to see the whole image → Click New Inc ROI → Click on 4 points to define your region of interest → Hit Enter (Make sure to leave enough room for movement)
- Click Find Centroids → Dark Small Markers → Adjust all four parameters (defined below) until each marker is highlighted in Green → Click to All Frames
  - Threshold - Level of grey to be considered White
  - Center Proximity – Minimum distance between two markers to become one
  - Threshold Image % - Percentage of image that is white to be considered threshold
  - Max pixels per mark – Approx. number of pixels in a single marker

- Once finished all markers should be highlighted in Red → Right click and assign each marker a number
- If a yellow sign appears saying marker incidents than one of the markers was lost during tracking
  - You can go to individual frames and assign the marker to the right number
  - Or re-track using different parameters
  - File → Save and then File → Export – Centroids
- To generate JPG Images Open Reporter → File → Open → Find the file that you want to analyze
  - Click on File → Convert → To Image Stack → Save as desired
Per Policy RA-IRB-118, activities that the Rush IRB may determine do not represent human subjects' research and do not require submission in the Rush Research Portal (RRP) include the following categories. Please select the category that applies to your project. If none of these categories apply to your research, please submit the project through the Rush Research Portal.

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☐ Course-related activities designated specifically for educational or teaching purposes, where data is collected from and about human subjects as part of a class exercise or assignment but are not intended for use outside of the classroom (not intended to develop or contribute to generalizable knowledge).

☐ Case report(s) involving the observation of a patient or patients whose novel condition or response to treatment was guided by the care provider's judgment regarding the best interest of the individual and no comparison of data is taking place. Please note that Rush HIPAA policies must be followed.

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The submission must include the following items:

☐ completed form,
☐ a description of project goals and an abstract of the project including project methods,
☐ if the project involves the use/analysis of deceased individuals’ information or specimens, a completed "HIPAA Use/Disclosure without Authorization" form and material/data transfer agreement (when applicable),
☐ if the project will be conducted at an outside institution, a letter or other documentation of review must be included from the institution where the activities will occur that indicates the institution does not consider the activities to be human subjects’ research and/or require IRB review.

Signature of Investigator: __________________________  Date: 9/26/2012

Signature of Faculty Sponsor: __________________________  Date: ________________
(if applicable)

---

For IRB Administrative Staff Use:

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Qualifies as Non Human Subject Research: ☐ Yes / ☐ No

Date Investigator Notified: 10/11/12  Signature of Administrator: __________________________

1) Forward a copy of all documentation to the investigator for their files.
2) Attach copy of any correspondence (emails, fax cover sheets with confirmation of transmission) with the investigator and file in appropriate Fiscal Year folder.

Version 2 (July 2012)
JACQUELINE M. THOMAS

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- Direct mechanical soft tissue tests
- Perform compressive pressure tests on large joint constructs
- Dissect and evaluate the integrity of soft tissue and cadaveric specimens
- Conduct and evaluate data by Microsoft Excel®, TestWorks®, GraphPad Prism®, SAS®, and G-Power®
- Compile optical data using ImageJ® and DMASS® software
- Design and create the website for the Sports Medicine Research group (http://vwanglab.wordpress.com)
- Evaluate and apply current literature related to orthopedic research

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- Conduct validation and verification tests with a variety of laboratory instruments
- Complete tests with GLP
- Document data using GDP
- Validate data to ensure accuracy and quality control

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UIC Department of Mechanical Engineering
Director: Thomas Royston, Ph.D
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Research assistant
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- Classifying acoustic device based on FDA and customer requirements
- Evaluation and application of current literature related to acoustic detection research
- Calibration of piezoelectric sensor system for acoustic analysis
- Creation of silicon solution to maintain sterilization
- Construction of sensor array for acoustic device
- Testing coherence and signal of sensor array
- Utilizing Microsoft Excel® for data collection and interpretation for quality assurance
- Conducting trial tests on subject
- Analyzing sensitivity of sensor data through Matlab®
- Producing visual results of individual sensor data through Matlab®
- Present and discuss monthly progress reports to senior members of the research team
The Performance of an Impedance Sensor to Measure Volume

Research assistant

- Fabrication of microcatheter system used for measuring volume changes in hydrocephalic rats
- Utilization of ADINA® software to demonstrate dynamic pressure and volume changes in virtual 3-D models
- Development of CAD sensor and hydrocephalic 3-D models for conceptual purposes
- Conversion of 2-D MRI scans into 3-D hydrocephalic brain models using medical imaging software: Imagej®, MRicro®, and Mimics®
- Development of dynamic agarose and silicon brain models to test accuracy of volume sensors
- Gather raw voltage data through experimental testing using oscilloscope measurements to ensure proper sensor function
- Calibration of impedance volume sensors by varying components of circuit design
- Evaluation and application of current literature related to hydrocephalic and impedance sensor research
- Ensure quality control through data documentation and visual display using Microsoft Excel®
- Present weekly project updates and written reports to senior members of the research team

PUBLICATIONS

Gregory JM, MD; Klosterman EM, MA; Thomas JM, BS; Hammond J, DO, ATC; Shewman EF, MS; Wang VM, PhD; Verma NN, MD; Romeo AA, MD. “Biomechanical Comparison of Suture Techniques in Pectoralis Major Repair”. Manuscript submitted (American Journal of Sports Medicine)

Bruce B, MD; Hussey K, BS; Thomas JM, BS; Shewman EF, MS; Wang VM, PhD; Romeo AA, MD; Verma NN, MD; Cole BJ, MD MBA. “Biomechanical Properties and Suture Placement Relative to the Musculotendinous Junction for Arthroscopic Repair of Utilizing Trans osseous Equivalent Techniques”. Manuscript in preparation (American Journal of Sports Medicine)

PRESENTATIONS

Rush University 24th Annual Resident Thesis Day. Chicago, IL, USA (April 2013). Gregory JM, MD; Klosterman EM, MA; Thomas JM, BS; Hammond J, DO, ATC; Shewman EF, MS; Wang VM, PhD; Verma NN, MD; Romeo AA, MD. “Biomechanical Comparison of Suture Techniques in Pectoralis Major Repair”.

Rush University 24th Annual Resident Thesis Day. Chicago, IL, USA (April 2013). Bruce B, MD; Hussey K, BS; Thomas JM, BS; Shewman EF, MS; Wang VM, PhD; Romeo AA, MD; Verma NN, MD; Cole BJ, MD MBA. “Biomechanical Properties and Suture Placement Relative to the Musculotendinous Junction for Arthroscopic Repair of Utilizing Trans osseous Equivalent Techniques”.

American Orthopedic Society for Sports Medicine. New Orleans, LA USA (March 2014). Gregory JM, MD; Klosterman EM, MA; Thomas JM, BS; Hammond J, DO, ATC; Shewman EF, MS; Wang VM, PhD; Verma NN, MD; Romeo AA, MD. “Biomechanical Comparison of Suture Techniques in Pectoralis Major Repair”. Short Talk