Development of an analytical model for rotator cuff repairs

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INTRODUCTION

Currently, surgical repair of the rotator cuff tears is the gold standard for the treatment of these injuries. However, these repairs have a high retear rate of 20-90% due to factors not restricted to tear size, chronicity of the repair and rehabilitation protocol [1, 2]. Hence, there remains a critical need for a repair strategy that is both biologically stimulating and improves the mechanical performance of these repairs. This has led to a surge in the development of synthetic and biologic scaffolds over the last decade [3]. Despite, these advances very little is known of the role these scaffolds play in load sharing and in the biomechanics of the repair. The objective of the present study was to develop and validate analytical models of a primary and augmented tendon repair. We intend to use these models to investigate the mechanical role of the various components of the tendon repair.

MATERIALS AND METHODS

A. Model for primary and augmented repairs: The primary and augmented repairs were modeled using springs. The primary repair had two springs in series (Figure 1a): the bone-suture-tendon interface (spring#1) and the tendon (spring#2). The augmented repair had a total of five springs (Figure 1b). The tendon (spring#2) was divided in two springs, spring#2' and spring#2". The bone-scaffold-suture component (spring#3) and the scaffold-suture-tendon interface (spring#4) were in series with each other and together in parallel with the primary repair (spring 1 and 2'). The entire repair model was then placed in series with the other half tendon spring#2".

B. Spring mechanical properties: The properties of the individual springs were obtained experimentally using male cadaveric canine shoulders (~30kgs).

Spring#1 & Spring#2: Canine shoulders (n=5) had their infraspinatus (IFT) tendon released and repaired to the greater tuberosity using two transosseous Mason Allen sutures. The IFT muscle was freeze clamped and the repair was cycled between 5-100N for 100 cycles @ 0.25Hz and subsequently loaded to failure at 30mm/min. Optical markers were placed on the tendon near the insertion site and the tendon midsubstance to determine the properties of the spring#1 & #2. *Spring#3:* Woven PLLA devices (n=3) were screwed to a saw bone on one end and sutured with 3 simple stitches to a rod on the other end. The

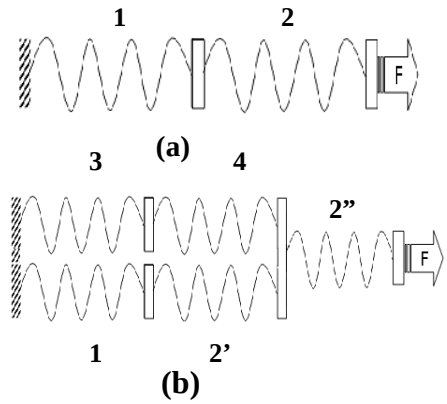

Figure 1: Schematic representation of (a) primary and (b) augmented rotator cuff repair.

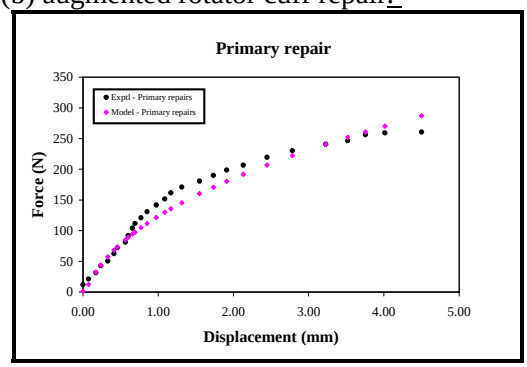

Figure 2: Load displacement plots for model predicted and experimental primary repair

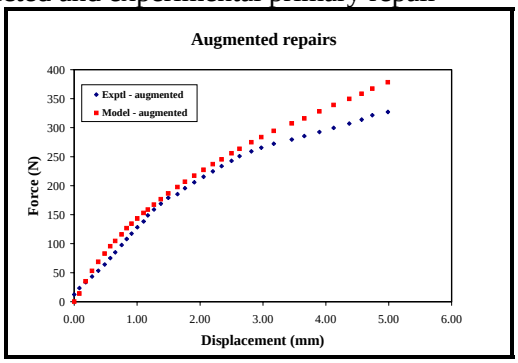

Figure 3: Load displacement plots for model predicted and experimental augmented repair

devices were preloaded to 5N and subsequently loaded to failure @ 30mm/min.

Spring#4: Three Mason Allen sutures were placed in isolated canine IFT tendons (n=5) and secured over a rod. The IFT muscle was frozen and the suture-tendon interface was cycled between 5-30N for 20 cycles @ 0.25Hz followed by load to failure at 30mm/min. The load-displacement properties of spring#3 & #4 were determined using actuator displacements.

C.Repair mechanical properties: For *primary repair constructs* the IFT tendons of five canine shoulders were released and repaired to the greater tuberosity. For *augmented repair constructs* IFT tendons of five canine shoulders were released and repaired to the greater tuberosity followed by augmentation with a woven PLLA device screwed to the bone. The surgical & testing protocol was similar to the respective individual springs described above.

D. Curve fitting*:* The average experimental data for each spring was fitted to a power law [F = A(x) ^b] up to the yield load, defined as the first maximum load attained by the specimen. The parameters A and b were determined using the Curve fitting toolbox in MATLAB (Mathworks, Natick, MA).

D. Model development and validation: A system of equations was developed for both, primary and augmented repair constructs, using the average curve-fit data from the individual component testing. The models were solved under static equilibrium conditions using the optimization toolbox in MATLAB. To validate the models, the model generated load (output) was obtained for a given displacement (input) and was compared to experimental data. The average RMS difference of the predicted versus experimental data was computed.

RESULTS

The RMS value for the primary model (13.8N) was 6% of the average experimental yield load (235.3±39N) (Figure 2). The RMS value for the augmented repair model (22.8N) was 7% of the yield load of the average experimental yield load (327±46.5N) (Figure 3). Experimentally no significant difference (ttest, $p>0.05$) was seen between the stiffness of the primary (132±27.5N/mm) and augmented (121±23.3N/mm) repair constructs. However, the model predicted stiffness of the augmented repair construct (122N/mm) was higher than the model predicted stiffness for the primary repair construct (92N/mm). The model also predicted that the augmentation component (springs #3 and #4) carries 25% of the yield load of the augmented repair construct.

DISCUSSION

The goal of this study was to develop a simple analytical model for primary and augmented tendon repair constructs. RMS below 10% suggests that developing a model using a spring analogy can predict the mechanical behavior of both the repair constructs with reasonable accuracy up to the point of maximum (yield) load. However, the model appears to predict an increase in stiffness with augmentation, which the experimental data does not support. We are currently computing the confidence intervals for our model predictions, in an effort to determine if this apparent difference in stiffness is statistically significant. One limitation of our model is that the parameters were obtained from failure testing of samples that were first subjected to a cyclical loading protocol. Hence, the model cannot be used to predict the biomechanical performance of the repairs upon the very first onset of mechanical load. Further, our model cannot be used to predict failure loads (complete rupture) as the model was developed only up to and including the point of maximum (yield) load. Finally, compared to the clinical scenario, the experimental repairs used to develop this model are greatly simplified. Hence the model is limited to making only general observations about the mechanical roles of the various components of a tendon repair.

CONCLUSIONS

In summary, we present here a simple, accurate model to estimate the mechanical behavior of primary and augmented tendon repair. We believe that the model will be useful for identifying the relative contributions of the various components of the repair construct and suggesting improvements to current repair strategies.

REFERENCES

1.Galatz LM, et al, JBJS 86A, 219-224, 2004.
2.Gaizelly DF, et al, COR, 304, 43-53, 2004.
3.Aurora A, et al, JSES, 16(Suppl 5), 171-8, 2007

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