MECHANICAL BEHAVIOUR OF TITANIUM IMPLANT DESIGNED FOR REPAIR OF ROTATOR CUFF TEARS

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Abstract. *Rotator cuff tears generate shoulder pain and functional disability. The surgical treatment is performed through arthroscopy using suture anchors. The anchors can be metallic or non-metallic and have suture threads. Its function is attach the tendon to the bone to improve the healing process. However, the difficulty of passing and tying threads increases the surgery time and the costs. Therefore, the aim of this paper was developing an alternative implant to the anchors that does not use suture threads. The mechanical strength of the titanium implant and anchor was evaluated by using a simplified tridimensional model of the humerus and supraspinatus tendon. The results showed that the mechanical strength of the proposed titanium implant was adequate and the von Mises stresses for the new implant were lower than the stresses for the suture anchor.*

Keywords*: Rotator cuff. Tears. Titanium Implant. Suture Anchor. Finite element analysis.*

1. INTRODUCTION

The rotator cuff is a group of four muscles (supraspinatus, infraspinatus, subscapularis and teres minor) that arise from the scapula and whose tendons attach to the tuberosities of the humerus. The tears of rotator cuff are a common cause of shoulder pain and functional disability affecting mostly elderly individuals (Minagawa, *et al.,* 2013). The supraspinatus tendon is the most frequently damaged soft tissue in the shoulder, due to its anatomical position and its particularly complex loading environment (Quental, *et al*., 2016).

The surgical treatment for the tear is made by arthroscopy, this technique became popular after the development of the suture anchors. The anchors have a body of material metallic or non-metallic and suture threads (Barber, *et al*., 2011; Galland, 2013). The attachment of tendon to bone is made by suture threads that can be tied with different configurations and knots. However, the disadvantage of this technique is the difficulty of guiding sutures through tendon and tying secure knots resulting in increased surgical time and costs. (Lee, *et al*., 2005).

The aim of this study is to design an alternative implant to suture anchors that does not use suture threads and evaluate its mechanical strength using a finite element model. With this alternative implant, the difficulties inherent in the passage and tying threads during the surgical procedure are excluded.

2. FINITE ELEMENT ANALYSIS

The alternative implant to the anchors has U-shaped geometry. The implant width is dependent of the maximum cannula diameter used in the shoulder arthroscopy that is 9 mm and height implant is 22 mm.

The mechanical strength of the proposed implant was evaluated in a simplified tridimensional (3D) model of humerus and supraspinatus tendon using finite element analysis Fig.(1A). In addition, a comparative model was developed to obtain the mechanical strength of the suture anchor Fig. (1B).

Three-dimensional finite element analysis was performed with the software Abaqus®.

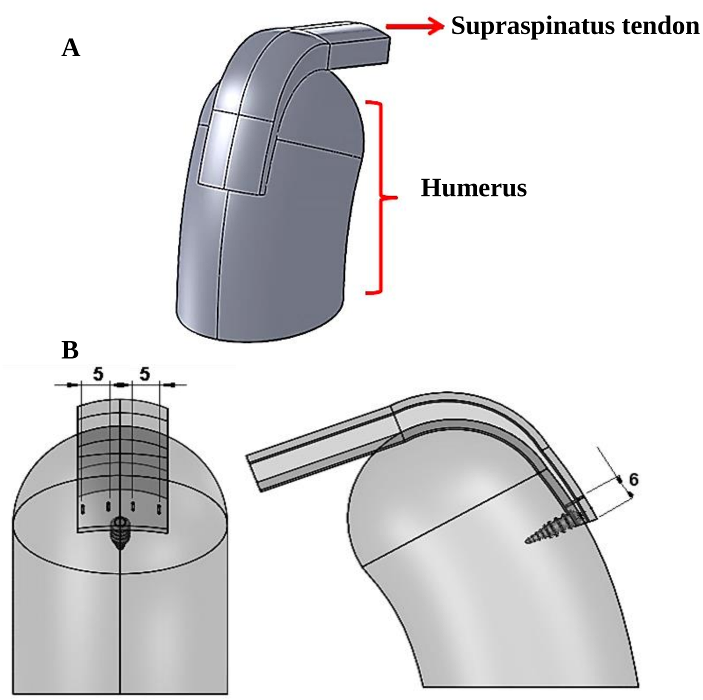

Figure 1. (A) Simplified 3D model of the rotator cuff; (B) Assembly of the rotator cuff repair done with the suture anchor.

The Table (1) shows the mechanical properties of the materials used in the finite element analysis. These properties were obtained from article of Sano *et al*. (2006) e Funakoshi *et al*. (2008).

Table 1 – Mechanical properties of materials.

Material	E (MPa)	ν
Supraspinatus tendon	168	0,497
Humerus (cancellous bone)	1380	0,300
Titanium	103400	0,350

In both models, the loads of infraspinatus (4 N) and subscapularis (5 N) tendons were applied in points near to the supraspinatus tendon. Tensile loads of 10 N, 30 N and 50 N were applied to the proximal end of the supraspinatus tendon. A load of 10 N was applied in the distal end of humerus Fig. (2) (Karlsson and Peterson,1992).

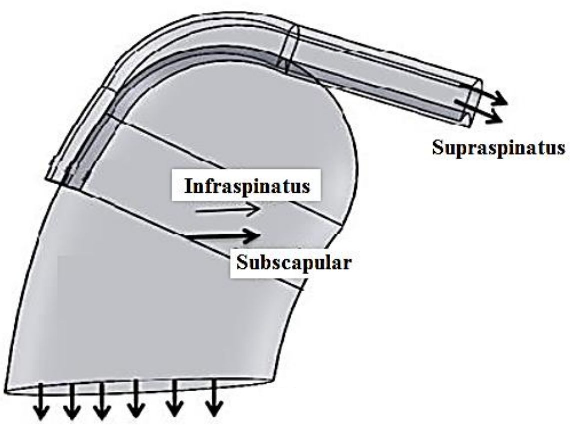

Figure 2. -Loads applied in the humerus/tendon.

In the model with the proposed implant a compression load of 30 N was applied in upper surface of implant. In the model with the anchor the loads were applied in four holes made in the tendon simulating the place where the suture threads would pass. In each hole three load components were considered: x-axis (Fx=10 N), load that simulate the approximation of the suture threads; y-axis (Fy=15 N), compression load that simulate the tying of knots and z-axis (Fz=22,5 N), tensile load that simulate the attachment of tendon to bone. These load values were obtained from a tensile tests using bovine tendon and humerus specimens. The repair of the tendon in these tests was done with a suture anchor. So, the loads were used as the basis to determine the loading conditions of the proposed implant and used to represent the action of the sutures in the repair with the suture anchor.

A line that surrounding diameter of the humerus was fixed on the x, y and z axes, in both models.

In the implant model the tendon/bone and bone/implant/tendon contact was defined as frictionless, in the anchor model, the tendon/bone contact was defined as frictionless and the bone/anchor/tendon contact was defined as tied.

The three-dimensional solid element C3D10 (10 nodes and 3 degrees of freedom) was used in Finite Element Analysis.

3. RESULTS AND DISCUSSION

The Table (2) shows the results for the maximum von Mises stresses in the proposed implant.

Table 2 – Maximum von Mises stresses in the implant for different loads applied in tendon.

Loads applied in tendon (N)	**Maximum von Mises stresses (MPa)**
10	44,22
30	47,89
50	74,40

In order to quantify the von Mises stresses in the tendon, a “path points” was defined in the proximal region of the implant insertion. That path points was marked on the articular side of the tendon. Figure (3A) shows points defined for stress analysis at the articular side of the tendon and Fig. (3B) illustrates the von Mises stress [MPa] versus analyzed points obtained for the tendon articular side. According to Fig. (3B) it can be seen that the values of stresses increased with the increase of the load applied on the tendon and the highest von Mises stress was approximately 3 MPa.

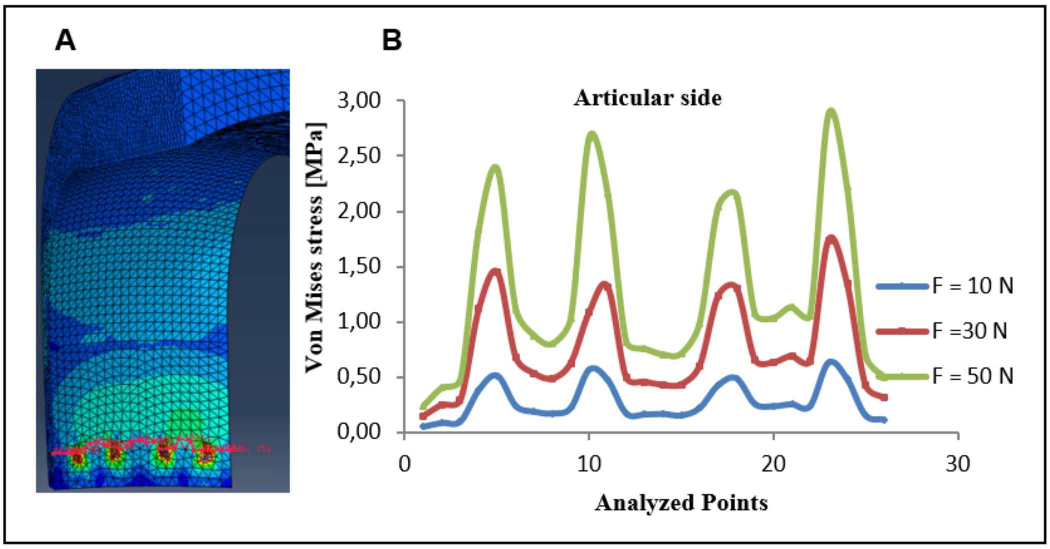

Figure 3. A – Path points defined on the articular side of the tendon. B – Von Mises stress [MPa] x analyzed points.

The loading conditions for the anchor was made in two steps. In the first step the knot tying and the attachment of tendon to bone was presented. In the second, loads of 10, 30 and 50 N were applied to the tendon. The Table (3) shows the maximum von Mises stresses for the anchor.

Table 3 – Maximum von Misses Stresses for the anchor for load steps 1 and 2.

Load step 1	Load step 2	
Maximum von Mises stresses (MPa)	**Loads applied in tendon (N)**	**Maximum von Mises stresses (MPa)**
240,17	10	227,63
240,17	30	199,65
240,17	50	171,58

Similar to the model with the proposed implant, in the anchor model a path points was defined on the articular side of the tendon to assess von Mises stresses. That path point was marked on the articular side of the tendon. Figure (4) shows points defined for stress analysis at the articular side of the tendon and Fig. (4B) illustrates the von Mises stress [MPa] versus analyzed points obtained for the tendon articular side. According to Fig. (4B) it can be seen that the values of stresses presented a greater difference between them in the region of contact between the anchor and tendon, also the highest von Mises stress was approximately 10 MPa.

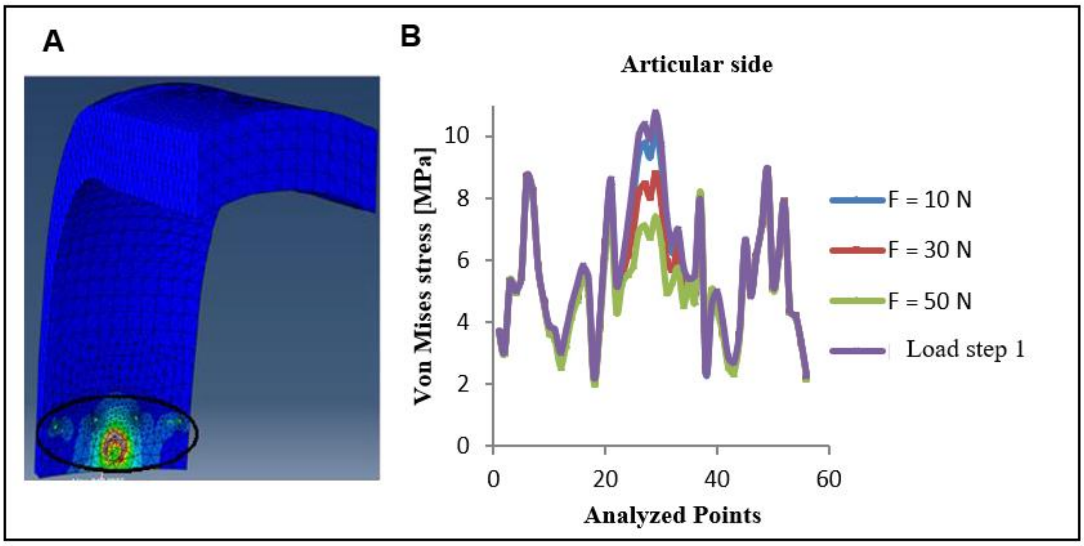

Figure 4. A – Path points defined on the articular side of the tendon; B- Von Mises stress [MPa] x analyzed points.

According to results, the implant showed lower stresses values than the anchors. However, both showed maximum von Mises stresses below the titanium yield strength that is 485 MPa (Ratner, et al., 2013)

Regarding the mechanical strength of the supraspinatus tendon, Itoi et al. (1995) evaluated the tensile properties of the supraspinatus tendon using eleven human cadaver shoulders with a mean age of 64 years old. The results showed that the tendon rupture stress was 26 MPa. In the model of proposed implant it was observed that the highest von Mises stress was about 3.5 MPa, and the anchor model the highest von Mises stress was about 10 MPa. Therefore, the stress values for the tendon in both models was below the tendon rupture stress obtained by Itoi et al. (1995).

4. CONCLUSION

The numerical modelling showed that mechanical strength of the proposed titanium implant was adequate for the boundary and loading conditions imposed to the finite element model and the von Mises stresses for the proposed implant were lower than the stresses in the anchor model.

5. REFERENCES

BARBER, F. A.; HERBERT, M. A.; HAPA, O.; RAPLEY, J. H.; BARBER, C. A. K.; BYNUM, J. A.; HRNACK, S. A. **Biomechanical analysis of pullout strengths of rotator cuff and glenoid anchors: 2011 update**. Arthroscopy: The Journal of Arthroscopic and Related Surgery, v. 27, p. 895 - 905, 2011.

FUKONASHI, T.; SUENAGA, N.; SANO, H.; OIZUMI, N.; MINAMI, A.**In vitro and finite element analysis of a novel rotator cuff fixation technique**. Journal of Shoulder and Elbow Surgery, v. 17, p. 986-992, 2008.

GALLAND, A.; AIRAUDI S.; GRAVIER, R.; CANN, S.L.; CHABRAND, P.; ARGENSON J.N. **Pullout strength of all suture anchors in the repair of rotator cuff tears: a biomechanical study.** International Orthopaedics, v. 37, p. 2017-2023, 2013.

ITOI, E.; BERGLUND, L. J.; GRABOWSKI, J. J.; SCHULTZ, F. M.; GROWNEY, E. S.; MORREY, B. F.; AN, K.-N. **Tensile properties of the supraspinatus tendon**. Journal of Orthopaedic Research, v. 13, p. 578-584, 1995.

KARLSSON, D.; PETERSON, B. **Towards a model for force predictions in the human shoulder**. Journal of Biomechanics, v. 25, p. 189-199, 1992.

LEE, S.; MAHAR, A.; BYNUM, K.; PEDOWITZ, R. **Biomechanical comparison of bioabsorbable sutureless screw anchor versus suture anchor fixation for rotator cuff repair.** Arthroscopy: The Journal of Arthroscopic and Related Surgery, v. 21, p. 43-47, 2005.

MINAGAWA, H. et al**. Prevalence of symptomatic and asymptomatic rotator cuff tears in the general population: from mass-screening in one village.** Jounral of Orthopaedics, v. 10, p. 8-12, 2013.

QUENTAL, C.; FOLGADO, J.; MONTEIRO, J.; SARMENTO, M. **Full thickness tears of the supraspinatus tendo: a three-dimensional finite elemento analysis.** Journal of Biomechanics, v.49, p.3962-3970, 2016**.**

RATNER, B. D.; HOFFMAN, A. S.; SCHOEN, F. J.; LEMONS, J. E.**Biomeaterials science: an evolving, multidisciplinary endeavor**. In: RATNER, B., et al. Biomaterials science: an introduction to materials in medicine. 3. ed. 2013. p. 1525.

SANO, H.; WAKABAYASHI, I.; ITOI, E. **Stress distribution in the supraspinatus tendon with partial-thickness tears: an analysis using two-dimensional finite element model.** Journal of Shoulder and Elbow Surgery, v. 15, p. 100-105, 2006.

6. ACKNOWLEDGEMENTS

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