



## Original article

# Biomechanical evaluation of the long head of the biceps brachii tendon fixed by three techniques: a sheep model<sup>☆</sup>



Carlos Henrique Ramos\*, Júlio Cezar Uili Coelho

Universidade Federal do Paraná, Curitiba, PR, Brazil

## ARTICLE INFO

## Article history:

Received 22 February 2016

Accepted 18 March 2016

Available online 30 December 2016

## Keywords:

Biceps braquii

Humerus

Biomechanic

Tendons

## ABSTRACT

**Objective:** To evaluate the biomechanical properties of the fixation of the long head of the biceps brachii into the humeral bone with suture anchors, interference screw, and soft tissue suture, comparing strength, highest traction load, and types of fixation failure.

**Methods:** Thirty fresh-frozen sheep shoulders were used, separated into three groups of ten for each technique. After fixation, the tendons were subjected to longitudinal continuous loading, obtaining load-to-failure (N) and displacement (mm).

**Results:** The mean load-to-failure for suture anchors was  $95 \pm 35.3$  N,  $152.7 \pm 52.7$  N for interference screw, and  $104.7 \pm 23.54$  N for soft tissue technique. There was a statistically significant difference ( $p < 0.05$ ), with interference screw demonstrating higher load-to-failure than suture anchor fixation ( $p = 0.00307$ ) and soft tissue ( $p = 0.00473$ ). The strength of interference screw was also superior when compared with the other two methods ( $p = 0.0000127$  and  $p = 0.00000295$ , respectively). There were no differences between suture anchors and soft tissue technique regarding load-to-failure ( $p = 0.9420$ ) and strength ( $p = 0.141$ ).

**Conclusion:** Tenodesis of the long head of the biceps brachii with interference screw was stronger than the suture anchors and soft tissue techniques. The other two techniques did not differ between themselves.

© 2016 Sociedade Brasileira de Ortopedia e Traumatologia. Published by Elsevier Editora Ltda. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

## Avaliação biomecânica da fixação do tendão da cabeça longa do bíceps braquial por três técnicas: modelo em ovinos

## RESUMO

**Objetivo:** Avaliar biomecanicamente a fixação da cabeça longa do bíceps braquial no úmero com âncoras ósseas, parafuso de interferência e sutura em partes moles e comparar resistência, força máxima de tração e tipos de falha na fixação.

## Palavras-chave:

Bíceps braquial

Úmero

<sup>☆</sup> Study conducted at the Centro Universitário (UniBrasil), at the Pontifícia Universidade Católica do Paraná, and at the Universidade Federal do Paraná, Curitiba, PR, Brazil.

\* Corresponding author.

E-mail: [chramos@hotmail.com](mailto:chramos@hotmail.com) (C.H. Ramos).

<http://dx.doi.org/10.1016/j.rboe.2016.12.008>

2255-4971/© 2016 Sociedade Brasileira de Ortopedia e Traumatologia. Published by Elsevier Editora Ltda. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Biomecânica  
Tendões

**Métodos:** Foram usados 30 ombros de ovinos frescos, divididos em três grupos de dez para cada técnica. Após fixação, os tendões foram submetidos a tração longitudinal contínua até falha do sistema e obtiveram-se força máxima de tração (N) e deslocamento (mm).

**Resultados:** A força máxima de tração foi em média  $95 \pm 35,3$  N para âncoras ósseas,  $152,7 \pm 52,7$  N para parafuso de interferência e  $104,7 \pm 23,54$  N para partes moles. Houve diferença estatisticamente significativa ( $p < 0,05$ ): o parafuso de interferência demonstrou força máxima de tração superior às fixações com âncoras ósseas ( $p = 0,00307$ ) e partes moles ( $p = 0,00473$ ). A resistência com parafuso de interferência também foi superior à dos outros dois métodos ( $p = 0,0000127$  e  $p = 0,0000029,5$  respectivamente). Âncoras ósseas e partes moles não apresentaram diferenças, tanto para força máxima de tração ( $p = 0,9420$ ) quanto para resistência ( $p = 0,141$ ).

**Conclusão:** A tenodese da cabeça longa do bíceps braquial com parafuso de interferência demonstra maior resistência quando comparada com as técnicas com âncoras ósseas e partes moles. As duas últimas técnicas não diferem.

© 2016 Sociedade Brasileira de Ortopedia e Traumatologia. Publicado por Elsevier Editora Ltda. Este é um artigo Open Access sob uma licença CC BY-NC-ND (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

## Introduction

Disorders of the long head of biceps brachii tendon (LHBBT) are frequent causes of shoulder pain. Treatment should be conservative (analgesics, anti-inflammatories, and physiotherapy, among others); however, when conservative treatment is unsuccessful, surgery is indicated. The recommended procedure is tenotomy of the long head of the biceps (sectioning the tendon at the level of its insertion in the glenoid cavity) with or without tenodesis of the long head of the biceps (fixating the biceps tendon into the bicipital groove of the humerus). Tenodesis has been suggested as advantageous over isolated tenotomy, as it maintains the length/tension ratio and the flexion and supination strength of the elbow, preventing atrophy, pain at the site, and cosmetic deformity. Recent advances have allowed tenodesis to be preferably performed arthroscopically, which, despite promoting results similar to open surgery, offers advantages such as smaller surgical wound, lower post-operative pain, preservation of the deltoid muscle, and earlier return to activities, especially when associated with simultaneous repair of the rotator cuff.<sup>1-3</sup> Among the arthroscopic fixation methods, the most frequently used are bone anchors, interference screw (IS), and soft tissue suture without the need for implants.<sup>1,2,4-8</sup> Early postoperative mobilization of the upper limb is important for recovery, but may endanger tenodesis with possible release of the tendon. To avoid this issue, the system that provides the highest resistance should be used. Another aspect is the increased cost of the procedure when implants are used; soft tissue technique is cheaper. Identifying which method is more resistant would justify the use or non-use of implants, defining the most cost-effective technique. There is no consensus in the literature regarding which fixation method is more resistant.<sup>9-24</sup> This study aimed to compare three techniques for fixation of the LHBBT in the humerus (bone anchors, IS, and soft tissue suture) regarding

resistance of the fixation, load-to-failure (LTF), and system failure.

## Materials and methods

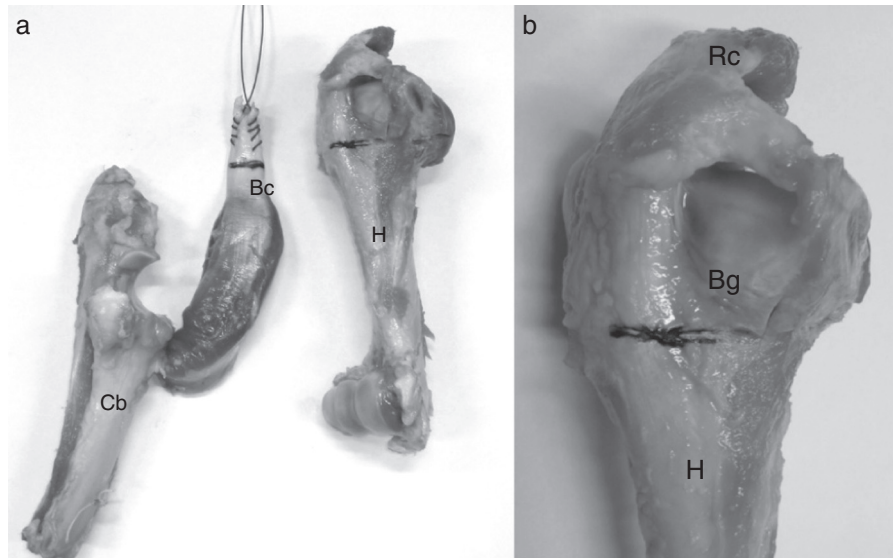
After approval by the Research Ethics Committee of the Hospital do Trabalhador of Universidade Federal do Paraná, 30 fresh shoulder specimens from skeletally immature Texel sheep, aged between six and 12 months, were acquired from a specialized company. The specimens were frozen immediately after slaughter and were kept at  $-20^{\circ}\text{C}$  until 24 h before preparation. Samples were then thawed at room temperature to undergo tenodesis. Samples were prepared with dissection of the humeral bone; only the biceps and the anterior portion of the rotator cuff inserted into the greater tuberosity of the humerus were preserved. The proximal biceps tendon was sectioned at the glenoid labrum in the upper portion of the glenoid cavity (scapular bone), maintaining its distal insertion into the cubitus bone (Fig. 1). The specimens were divided into three groups of ten, according to the type of tenodesis; ten pieces were thawed at a time, with an interval of 15 days between each test.

### Tenodesis with bone anchors

After two holes were made in the humeral metaphyseal region (bicipital groove), two bone anchor screws, made of titanium, with a diameter of 4.0 mm, positioned with an Ethibond 2<sup>®</sup> suture (braided polyester) were inserted with a distance of 5 mm between them (Fig. 2). Then, the biceps tendon was fixated into the humerus with a single stitch in each anchor (Fig. 3).

### Tenodesis with interference screw

The metaphyseal humeral region (biceps groove) was drilled at 2 cm from the apex of the humeral head with a bone drill that matched the diameter and length of the screw



**Fig. 1 – Photograph of the parts obtained by dissection; the distal insertion of the biceps in the cubitus bone (a) and the rotator cuff to the humerus (b) were maintained, Cb, cubital bone; Bc, biceps; Bg, bicipital groove; H, humerus; Rc, rotator cuff.**

(7 × 20 mm). The free end of the tendon was repaired using continuous suture with Ethibond 2<sup>®</sup> and inserted into the humeral orifice for fixation with IS, parallel to the tendon fibers (Figs. 4 and 5). During screw insertion, the tendon was kept in traction against the opposite cortex through prior transfixation of the repair wire with a fenestrated steel guidewire to keep it within the bone hole.

#### *Biceps tenodesis in soft tissue*

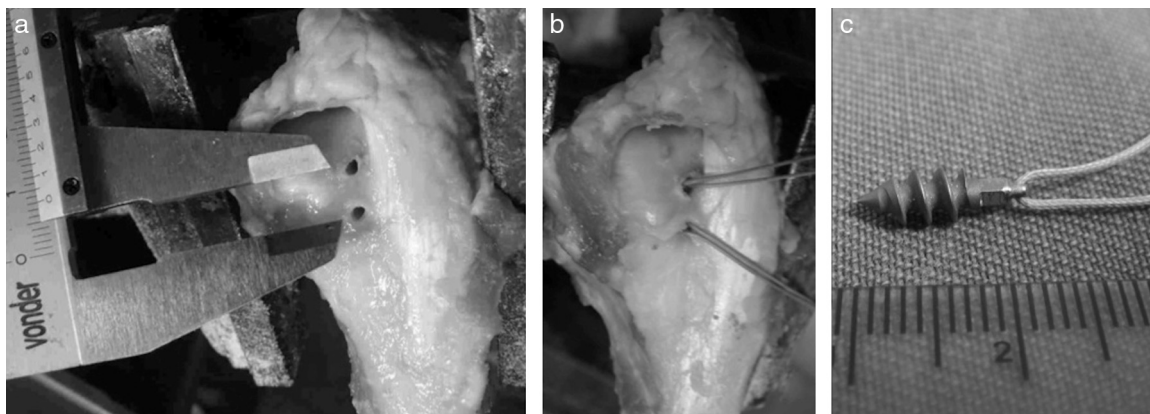
The bicipital tendon suture was made on the remaining portion of the rotator cuff that was maintained in the greater tuberosity of the humerus, with three simple stitches using Ethibond 2<sup>®</sup> sutures (Fig. 6).

Measurements were made with a Vonder<sup>®</sup> precision metallic caliper (150 mm-6"). After surgical preparation, material was sent to the Biomechanics Laboratory of the Universidade Tecnológica Federal do Paraná (UTFPR) for testing.

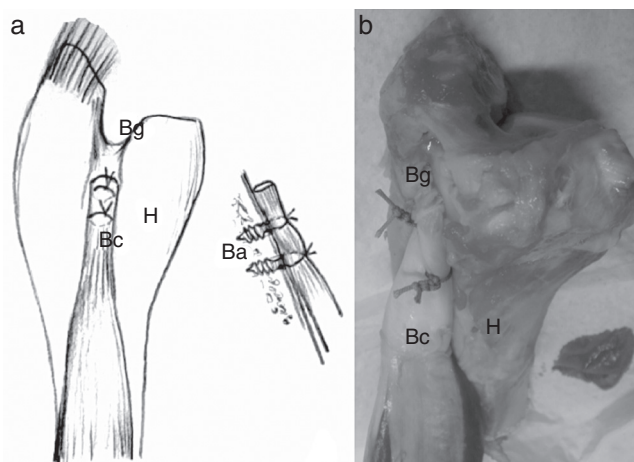
For axial traction, the universal MTS 810 (100 kN) hydraulic equipment for tensile tests was used, with a second actuator

(MTS 242.02) adapted with a load cell (model 661.19F-02, MTS Systems Corporation, with a capacity of 10 kN), and applied at a speed of 5 mm/min.

Models were fitted so that the traction to be exerted in the longitudinal direction in relation to the axes of the tendon and humerus would simulate the normal direction of contraction by the biceps. Iron devices were developed and placed on the tensile equipment to fixate the ends of the specimen. At the top, the ulnar bone was supported on this device and the tendon was passed through the center hole. For lower stabilization, a cylindrical adapter was fixed on the traction table. This piece had interior lateral perforations for humeral stabilization, with two strong steel wires of a diameter (5 mm), cross-transfixed in the metaphyseal region. The distance between the extremities varied according to the length of the muscle/tendon pair. For a better fit, the length of the humerus was cut at the middle third during assembly (Fig. 7). With the help of MTS-Test Star II software, 790.90, TestWorks – 1994, graphics indicating the LTF (N) were made. LTF was defined



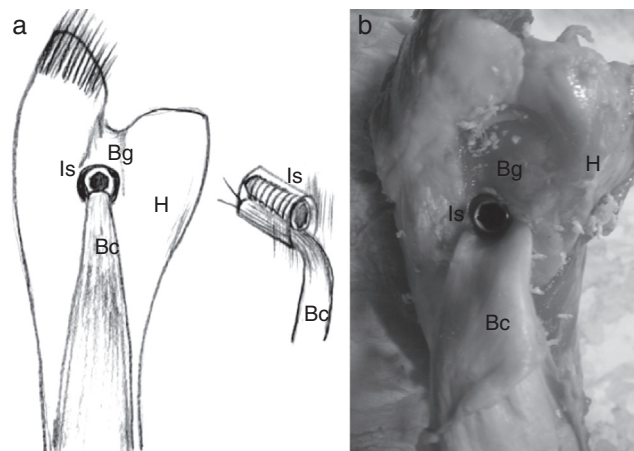
**Fig. 2 – Photographs showing the humeral preparation with bone perforations (a), insertion of the anchors in the bicipital groove (b) and type of anchor used (c).**



**Fig. 3 – Drawing (a) and specimen photograph (b) showing the fixation technique with bone anchors. Ba, bone anchors; Bc, biceps; Bg, bicipital groove; H, humerus.**

as the force required to break the fixation (system failure), obtained with peak of the curve, represented by the vertical axis of the graph. The system was considered to have failed when it lost tensile strength, whether by tendon slip or loosening or rupture of the fixation, even in cases without complete separation of the tendon-bone system. The dislocation until failure was represented by the horizontal axis. Resistance was calculated by dividing the LTF by the dislocation (Fig. 8).

The results were statistically analyzed with Kaplan-Meier non-parametric estimation of the survival function. The 95% confidence intervals for the probability of the system not failing until a certain force (LTF and resistance) were compared for every method. For quantitative evidence, the logrank significance test was used and the  $p$ -value was calculated (significant at  $p < 0.05$ ).

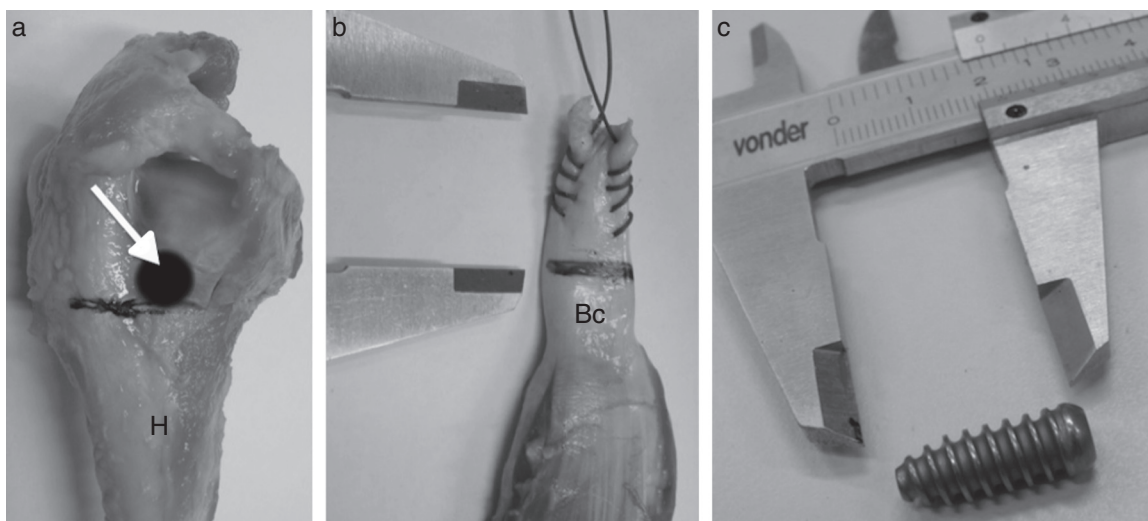


**Fig. 5 – Drawing (a) and specimen photograph (b) showing the fixation technique with interference screw. Bc, biceps; Bg, bicipital groove; Is, interference screw; H, humerus.**

The tests were done with Microsoft<sup>®</sup> Excel XP and Origin 6.1 Pro<sup>®</sup> programs. For the statistical analysis and adjustment of the reliability/survival models, the statistical software R, which is open source, was used.

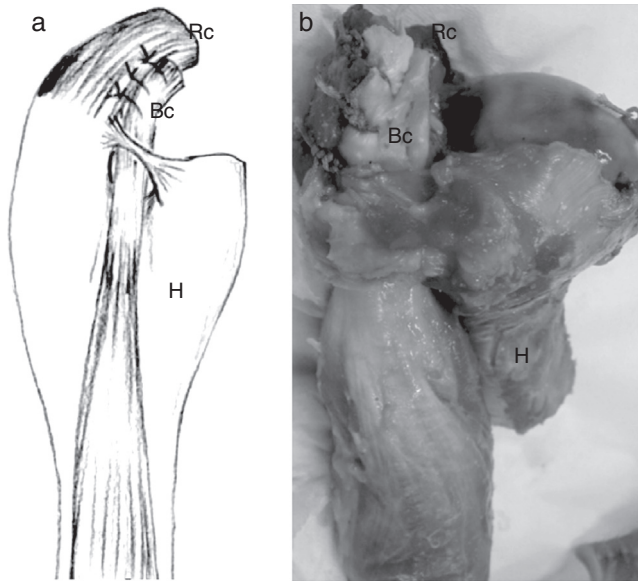
## Results

The LTF and resistance results for the three methods, presented as maximums, minimums, and means, are described in Tables 1 and 2. The central data values, dispersion, and possible outliers are shown in box-plot graphs for the same variables (Fig. 9). The mean LTF for the three methods was:  $95 \pm 35.3$  N (range 50–156 N) for bone anchors;  $52.7 \pm 152.7$  N (57–212 N) for IS;  $104.7 \pm 23.54$  N (75.9–145 N) for soft tissues. In the technique with bone anchors, failure occurred mainly at the junction of the suture in the tendon (nine tests), with fiber tear in the longitudinal direction without release of the bone



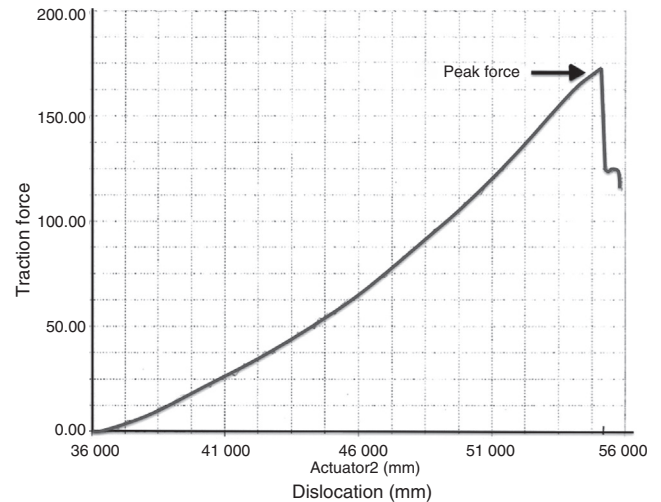
**Fig. 4 – Photographs showing the fixation technique with interference screw: humeral perforation (arrow) (a), tendon repair (b) and type of screw (c) Bc, biceps; H, humerus; Arrow, humeral drilling.**





**Fig. 6 – Drawing (a) and specimen photograph (b) showing the fixation technique in soft tissue. Bc, biceps; Rc, rotator cuff; H, humerus.**

anchor(s) (Fig. 10). In one test, a suture at the distal anchor failed, and a tendon rupture was observed in the suture. In the tests with IS, failure occurred mainly due to tendon slip (eight tests), and there were no cases of implant loosening (Fig. 11). In two cases, the failure occurred due to a rupture in the myotendinous junction, without loosening of fixation. All tests with soft tissue fixation presented failure by tendon slip; the sutures in the biceps and rotator cuff fibers remained intact. The Kaplan–Meier curves and the logrank  $p$ -values applied to the three methods studied demonstrated that the fixation with IS is significantly different ( $p < 0.05$ ) from the

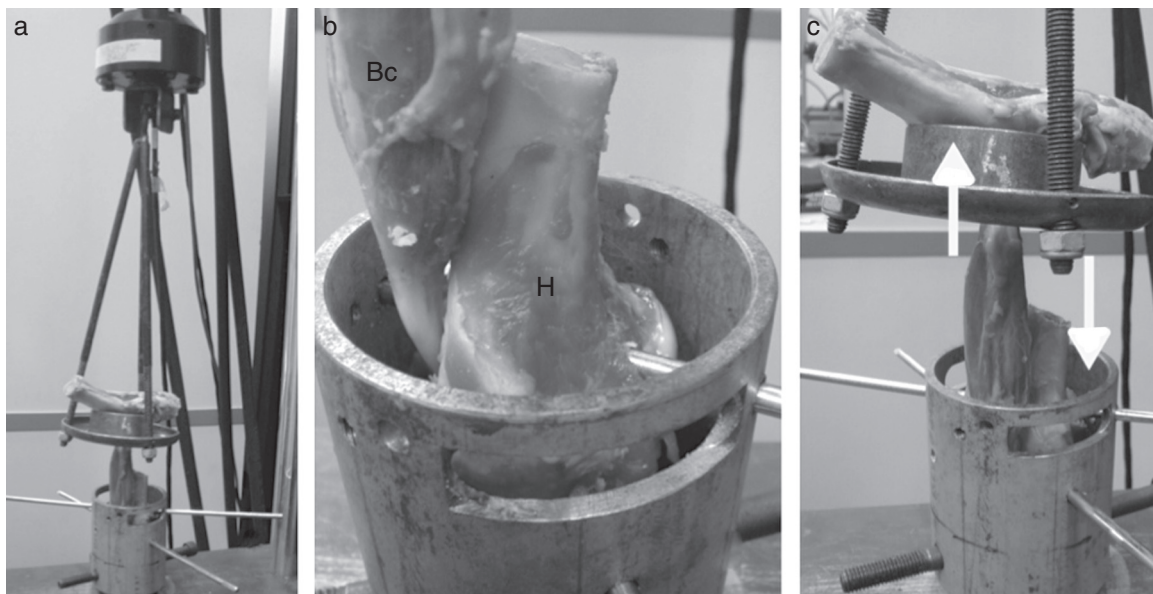


**Fig. 8 – Values recorded for peak force and displacement until system failure.**

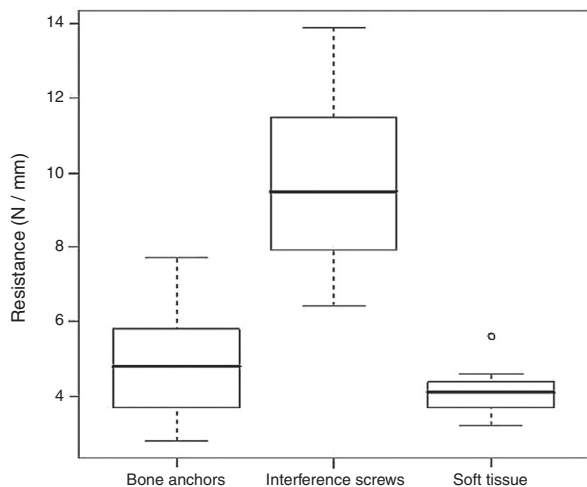
other methods, presenting higher LTF when compared with fixation with bone anchors ( $p = 0.00307$ ) and soft tissue suture ( $p = 0.00473$ ). IS resistance was also superior to the other two methods ( $p = 0.0000127$  and  $p = 0.00000295$ , respectively). Bone anchors and soft tissue suture did not differ significantly for both LTF ( $p = 0.9420$ ) and resistance ( $p = 0.141$ ).

## Discussion

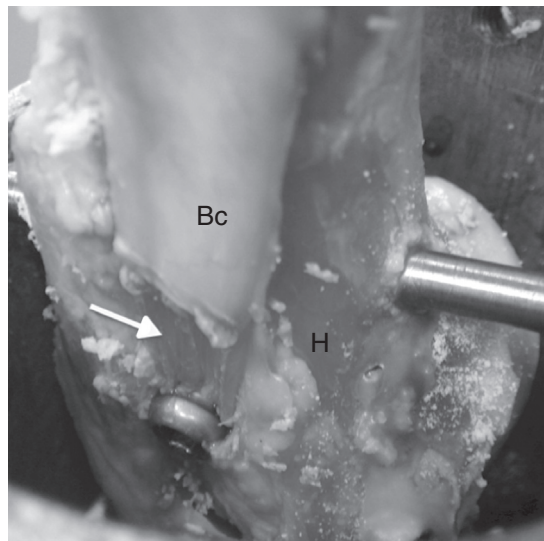
Tenodesis of the long head of the biceps has been preferably performed by arthroscopy, and safe fixation must ensure early return to postoperative mobilization without release of the tendon.<sup>2</sup> Among the most commonly used fixation methods (soft tissue suture, bone fixation with bone anchors, and IS)



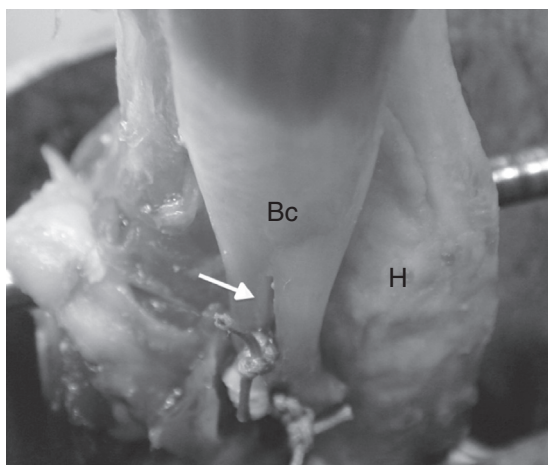
**Fig. 7 – Photos showing the final assembly of the model (a), humeral fixation with transfixed steel wires (b) and direction/axis of the traction (arrows) (c) Bc, biceps; H, humerus; Arrows, direction of traction.**



**Fig. 9 – Central data values, dispersion, and possible outliers of the long head of the biceps strength after tenodesis by bone anchors, interference screw, and soft tissue fixation without implant (n = 30).**



**Fig. 11 – Specimen photograph showing the slip of the tendon fixated with interference screw (arrow). Bc, biceps; H, humerus; Arrow, tendon slip.**



**Fig. 10 – Specimen photograph showing suture slip in the tendon due to tear in the test with bone anchors (arrow). Bc, biceps; H, humerus; Arrow, tendon tear.**

**Table 2 – Resistance of the tendon of the long head of the biceps after tenodesis with bone anchors, interference screw, and soft parts suture without implant (n = 30).**

	Bone anchors N/mm	IS N/mm	Soft tissue N/mm
Mean	4.7	9.9	4.1
Maximum	7.7	13.9	5.6
Minimum	2.8	6.4	3.2
SD	1.5	2.3	0.6

SD, standard deviation; n, number of tests; N, Newton/mm; IS, interference screw.

**Table 1 – Load-to-failure of the tendon of the long head of the biceps after tenodesis with bone anchors, interference screw, and soft parts suture without implant (n = 30).**

	Bone anchors N	IS N	Soft tissue N
Mean	95	152.7	104.7
Maximum	15	212	145
Minimum	50	57	75.9
SD	35.3	52.7	23.5

SD, standard deviation; n, number of tests; N, Newton; IS, interference screw.

there is no consensus on which offers greater resistance. Most studies have compared the resistance between bone anchors and IS; there is less information regarding soft tissue suture. No studies that compared the three types were retrieved in the literature. Nevertheless, according to the literature, the mean LTF for bone anchors is 188 N, ranging from 68.5 N to 310 N. For IS, the mean is 241 N (159–480 N) and for soft tissue fixation, the mean is 179 N (142–216 N).<sup>9-24</sup> In the present study, these values were 95 N, 152.7 N, and 104.7 N, respectively; when compared separately with the literature, these values were lower for the three methods. This difference can be attributed to the different methodologies adopted, or to factors such as types of specimens (human cadavers, sheep, pigs), bone density, nature of the implants (metal, bioabsorbable), different types of sutures and bone anchors, frequency in the displacement of traction throughout the tendon, or surgical technique. For bone anchors and soft tissue sutures, simple sutures were made. U-type or loop sutures can modify the resistance to the test.<sup>22,25</sup> Alterations can also occur with use of one or two anchors, as two-implant models are generally

more resistant.<sup>14</sup> Anchors prepared with double wire have also showed greater resistance.<sup>21</sup> Another factor is the difference observed between cyclical or continuous tensile tests. The present study followed a similar model to that described by Bradbury et al.,<sup>18</sup> who tested biceps resistance with continuous traction and justified that fixation failures would occur postoperatively in a single, sudden flexion or supination movement of the forearm, unlike the plastic deformation simulated by cyclic testing. Nonetheless, those authors suggested that cyclic tests should be used for comparing techniques, due to the possibility of variation. This can be considered one of the limitations of the present study. Although some authors included other techniques in their studies, some comparisons between IS and bone anchors were retrieved in the literature. Most showed a statistically significant difference. This suggests that fixation with IS provides greater resistance compared with bone anchors.<sup>10,12,15,16,22</sup> Other studies observed no statistical difference between these techniques, despite the fact that the LTF was always higher for fixation with IS.<sup>11,14,19-21,23</sup> Regarding soft tissue fixation, two biomechanical studies that compared bone anchors with IS were retrieved in the literature, and no statistical difference in resistance was observed in both studies. Nevertheless, in the second study, the soft tissue suture was made in the tendon of the pectoralis major muscle with more than two stitches, which may explain the higher LTF when compared with IS.<sup>17,24</sup> The present study demonstrated that IS fixation is more resistant and presents higher LTF than the other two methods. The main mechanism of failure in the IS method in the present study was tendon slip without screw loosening, observed in 80% of the tests. In only two situations was the system resistance higher, with failure at the myotendinous junction. This situation is similar to the literature, which indicates that failures in the implant-bone system are rare.<sup>26</sup> In the methods with bone anchors and soft tissue, failure occurred mainly in the tendon-suture junction, without wire rupture or implant release. Failures occurred in the longitudinal direction of the tendon fibers and of the tensile forces, which produced tear. Lopez-Vidriero et al.<sup>17</sup> observed the same effect and concluded that the quality of the tendon is important for these two types of fixation. Another possible failure is due to a wire rupture at the junction with the anchor; other authors indicated that these represent the majority of cases. In these, failure may occur due to lower resistance and quality of the suture or due to the quality of the anchor, as irregularities in the wire passage hole would cause greater friction and would make the wire fragile.<sup>10,12,27,28</sup> For practical comparisons regarding the safety of tenodesis, the observations by Jazrawi et al. should be added<sup>29</sup>: those authors defined 52 N as the mean force exerted on the biceps tendon to keep the arm in flexion without resistance, and 110 N as the force to sustain 1 kg. When performing tenotomy without fixation, the possibility of retraction of the tendon is high, as demonstrated by Wolf et al. after mean traction of only 110 N caused migration.<sup>13</sup> Even with the articular portion of the thickened tendon (the common degenerative process), failure occurs on average after traction of 33 N.<sup>30</sup> Attempts to increase resistance with preservation of the superior portion of the labrum at the biceps during tenotomy were not shown to be safe, with medium strength of only 73 N.<sup>18</sup>

Therefore, tenodesis should be performed when the objective is to prevent retraction of the tendon. With this data, even with the lower resistance values observed in the present study when compared with the literature, the authors suggest that all three techniques would be safe for early active postoperative mobilization of the upper limb, provided that this mobilization is made no weight or resistance. Nevertheless, significant fluctuations were observed; in one study with bone anchors, fixation failed at 50 N traction, and in one study with IS, failed at 57 N. Fixation with IS, despite demonstrating greater mean resistance, presented a higher standard deviation with greater variation of high and low values. Perhaps this technique is more susceptible to errors under greater influence of factors such as variations in the ratio of screw diameter/tendon and/or bone hole, as well as bone and/or tendon quality. Other factors to be considered are variations that can occur in surgical procedures, including surgical technique and surgeon's experience. This could justify the oscillations; however, in the present study's methodology, these variables were carefully kept equal. Brand et al.<sup>31</sup> demonstrated that bone density may interfere with the resistance of IS fixation. This factor should be taken into if the fixation is made at the supra or sub-pectoral level, especially if performed in patients with osteoporosis. Moreover, variable diameters of the tendon, of the screw, and of the bone drilling, as well as the nature of the implant (metallic or bioabsorbable), do not appear to interfere with the ultimate resistance.<sup>32,33</sup> The techniques with bone anchors and soft tissues, albeit offering less resistance, were more constant. Other studies are needed to explain this finding. Some considerations can be made about the use of the three techniques: in elderly patients or patients with osteoporosis, fixation of LHBTT in the soft tissues may be more resistant than bone anchors and IS, which depend on good bone quality. Similarly, soft tissue suture should perhaps be avoided in situations in which tendons are affected by degeneration, thus presenting poor quality. Young patients with good bone quality and higher functional demands would be favorable candidates for the use of implants. This profile includes patients who need greater security in the fixation, cases in which IS is preferred to bone anchors. If the cost factor is relevant, soft tissue fixation could be justified if tendon quality is favorable.

---

## Conclusion

The LHBTT fixation method with IS is more resistant than fixation with bone anchors and soft tissue technique. No statistically significant difference in resistance was observed between the latter two methods. The fixation method with IS presents a significantly higher LTF when compared with bone anchors and soft tissues methods. No statistically significant difference in LTF was observed between the latter two methods. Main failure mechanism of IS fixation is tendon slip. In fixation with bone anchors and/or soft tissue fixation, failure occurs predominantly due to tendon rupture. No failure due to implant loosening was observed in the IS and bone anchor methods.



## Conflicts of interest

The authors declare no conflicts of interest.

## Acknowledgements

To Professor Mauro Albano and Edmar Stieven Filho for the guidance provided during this study. To Professor Dr. Paulo Borges and to the mechanical engineering undergraduate Roberto Luis de Assumpção for technical support in the tests performed in the laboratory of the Universidade Tecnológica Federal do Paraná.

## REFERENCES

- Checchia SL, Doneux PS, Miyazaki AN, Silva LA, Fregoneze M, Ossada A, et al. Biceps tenodesis associated with arthroscopic repair of rotator cuff tears. *J Shoulder Elbow Surg.* 2005;14(2):138-44.
- Checchia SL, Santos PD, Miyazaki AN, Fregoneze M, Silva LA, Leite FSF, et al. Avaliação dos resultados da tenodese artroscópica do biceps, utilizando-se parafuso de interferência bioabsorvível. *Rev Bras Ortop.* 2007;42(8):237-43.
- Gurnani N, van Deurzen DF, Janmaat VT, van den Bekerom MP. Tenotomy or tenodesis for pathology of the long head of the biceps brachii: a systematic review and meta-analysis. *Knee Surg Sports Traumatol Arthrosc.* 2016;24(12):3765-71.
- Boileau P, Krishnan SG, Coste JS, Walch G. Arthroscopic biceps tenodesis: a new technique using bioabsorbable interference screw fixation. *Arthroscopy.* 2002;18(9):1002-12.
- Gartsman GM, Hammerman SM. Arthroscopic biceps tenodesis: operative technique. *Arthroscopy.* 2000;16(5):550-2.
- Sekiya JK, Elkousy HA, Rodosky MW. Arthroscopic biceps tenodesis using the percutaneous intra-articular transtendon technique. *Arthroscopy.* 2003;19(10):1137-41.
- Gumina S, Carbone S, Perugia D, Perugia L, Postacchini F. Rupture of the long head biceps tendon treated with tenodesis to the coracoid process. Results at more than 30 years. *Int Orthop.* 2011;35(5):713-6.
- Lo IK, Burkhart SS. Arthroscopic biceps tenodesis using a bioabsorbable interference screw. *Arthroscopy.* 2004;20(1):85-95.
- Jayamoorthy T, Field JR, Costi JJ, Martin DK, Stanley RM, Hearn TC. Biceps tenodesis: a biomechanical study of fixation methods. *J Shoulder Elbow Surg.* 2004;13(2):160-4.
- Ozalay M, Akpinar S, Karaeminogullari O, Balcik C, Tasci A, Tandogan RN, et al. Mechanical strength of four different biceps tenodesis techniques. *Arthroscopy.* 2005;21(8):992-8.
- Mazzocca AD, Bicos J, Santangelo S, Romeo AA, Arciero RA. The biomechanical evaluation of four fixation techniques for proximal biceps tenodesis. *Arthroscopy.* 2005;21(11):1296-306.
- Richards DP, Burkhart SS. A biomechanical analysis of two biceps tenodesis fixation techniques. *Arthroscopy.* 2005;21(7):861-6.
- Wolf RS, Zheng N, Weichel D. Long head biceps tenotomy versus tenodesis: a cadaveric biomechanical analysis. *Arthroscopy.* 2005;21(2):182-5.
- Kilicoglu O, Koyuncu O, Demirhan M, Esenyel CZ, Atalar AC, Ozsoy S, et al. Time-dependent changes in failure loads of 3 biceps tenodesis techniques: in vivo study in a sheep model. *Am J Sports Med.* 2005;33(10):1536-44.
- Kusma M, Dienst M, Eckert J, Steimer O, Kohn D. Tenodesis of the long head of biceps brachii: cyclic testing of five methods of fixation in a porcine model. *J Shoulder Elbow Surg.* 2008;17(6):967-73.
- Golish SR, Caldwell PE 3rd, Miller MD, Singanamala N, Ranawat AS, Treme G, et al. Interference screw versus suture anchor fixation for subpectoral tenodesis of the proximal biceps tendon: a cadaveric study. *Arthroscopy.* 2008;24(10):1103-8.
- Lopez-Vidriero E, Costic RS, Fu FH, Rodosky MW. Biomechanical evaluation of 2 arthroscopic biceps tenodeses: double-anchor versus percutaneous intra-articular transtendon (PITT) techniques. *Am J Sports Med.* 2010;38(1):146-52.
- Bradbury T, Dunn WR, Kuhn JE. Preventing the Popeye deformity after release of the long head of the biceps tendon: an alternative technique and biomechanical evaluation. *Arthroscopy.* 2008;24(10):1099-102.
- Patzer T, Santo G, Olender GD, Wellmann M, Hurschler C, Schofer MD. Suprapectoral or subpectoral position for biceps tenodesis: biomechanical comparison of four different techniques in both positions. *J Shoulder Elbow Surg.* 2012;21(1):116-25.
- Tashjian RZ, Henninger HB. Biomechanical evaluation of subpectoral biceps tenodesis: dual suture anchor versus interference screw fixation. *J Shoulder Elbow Surg.* 2013;22(10):1408-12.
- Baleani M, Francesconi D, Zani L, Giannini S, Snyder SJ. Suprapectoral biceps a biomechanical comparison of a new soft anchor tenodesis technique versus interference screw biceps tendon fixation. *Clin Biomech (Bristol, Avon).* 2015;30(2):188-94.
- Patzer T, Rundic JM, Bobrowitsch E, Olender GD, Hurschler C, Schofer MD. Biomechanical comparison of arthroscopically performable techniques for suprapectoral biceps tenodesis. *Arthroscopy.* 2011;27(8):1036-47.
- Papp DF, Skelley NW, Sutter EG, Ji JH, Wierks CH, Belkoff SM, et al. Biomechanical evaluation of open suture anchor fixation versus interference screw for biceps tenodesis. *Orthopedics.* 2011;34(7):e275-8.
- Ahmed M, Young BT, Bledsoe G, Cutuk A, Kaar SG. Biomechanical comparison of long head of biceps tenodesis with interference screw and biceps sling soft tissue techniques. *Arthroscopy.* 2013;29(7):1157-63.
- Lafosse L, Van Raebroeckx A, Brzoska R. A new technique to improve tissue grip: the lasso-loop stitch. *Arthroscopy.* 2006;22(11):1246.e1-3.
- Koch BS, Burks RT. Failure of biceps tenodesis with interference screw fixation. *Arthroscopy.* 2012;28(5):735-40.
- Meyer DC, Nyffeler RW, Fucentese SF, Gerber C. Failure of suture material at suture anchor eyelets. *Arthroscopy.* 2002;18(9):1013-9.
- Deakin M, Stubbs D, Bruce W, Goldberg J, Gillies RM, Walsh WR. Suture strength and angle of load application in a suture anchor eyelet. *Arthroscopy.* 2005;21(12):1447-51.
- Jazrawi LM, Rokito AS, Birdzell MG, Zuckerman JD. Biomechanics of the elbow. In: Nordin M, Frankel VH, editors. *Basic biomechanics of the musculoskeletal system.* Philadelphia: Lippincott Williams & Wilkins; 2001. p. 340-57.
- Ahmad CS, DiSipio C, Lester J, Gardner TR, Levine WN, Bigliani LU. Factors affecting dropped biceps deformity after tenotomy of the long head of the biceps tendon. *Arthroscopy.* 2007;23(5):537-41.
- Brand JC Jr, Pienkowski D, Steenlage E, Hamilton D, Johnson DL, Caborn DN. Interference screw fixation strength of a quadrupled hamstring tendon graft is directly related to bone



- mineral density and insertion torque. *Am J Sports Med.* 2000;28(5):705-10.
32. Slabaugh MA, Frank RM, Van Thiel GS, Bell RM, Wang VM, Trenhaile S, et al. Biceps tenodesis with interference screw fixation: a biomechanical comparison of screw length and diameter. *Arthroscopy.* 2011;27(2):161-6.
33. Caborn DN, Coen M, Neef R, Hamilton D, Nyland J, Johnson DL. Quadrupled semitendinosus-gracilis autograft fixation in the femoral tunnel: a comparison between a metal and a bioabsorbable interference screw. *Arthroscopy.* 1998;14(3):241-5.