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Biomechanical Evaluation of 2 Arthroscopic Biceps Tenodeses

Double-Anchor Versus Percutaneous Intra-Articular Transtendon (PITT) Techniques

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Background: Recently, there is increasing interest in different arthroscopic biceps tenodesis techniques. However, little data have been published about the biomechanical properties of soft tissue tenodesis.

Purpose: This study was undertaken to evaluate the biomechanical properties of 2 different arthroscopic biceps tenodeses: the percutaneous intra-articular transtendon (PITT) technique and the suture-anchor technique.

Study Design: Controlled laboratory study.

Methods: Fifteen fresh-frozen cadaveric specimens were randomly allocated to the 2 different biceps tenodesis techniques. The humerus with biceps tenodesis was mounted on a materials testing machine to perform a load to failure test. The structural properties including ultimate load (N) and stiffness (N/mm) were derived from the load-displacement curve. The mode of failure was also recorded. Ultimate load and stiffness were compared with the parametric Student *t* test.

Results: Both repairs showed typical load-displacement curves followed by a constant increase in load and displacement until failure occurred. Suture-anchor and PITT techniques had ultimate loads of 175.4 ± 40.4 N and 142.7 ± 30.9 N ($P = .10$) and stiffness of 15.9 ± 8.4 N/mm and 13.3 ± 3 N/mm ($P = .36$), respectively, with no significant differences between them. All of the surgical constructs failed in the tendon site by pulling out with the sutures through the substance of the tendon.

Conclusion: The suture-anchor and PITT techniques exhibited satisfactory initial strength with no statistical difference between the 2 groups. These findings, along with the consistent pullout of the suture through the tendon during failure, suggest that the most important factor for initial strength is not the attachment site but the quality of the biceps tendon.

Clinical Relevance: The quality of the tendon should be taken into account when deciding the surgical technique and the rehabilitation program. The PITT technique has the benefit of avoiding hardware complications and cost.

Keywords: biceps tenodesis; arthroscopy; biomechanics; soft tissue tenodesis; anchor technique; PITT technique

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With the advent of arthroscopy, the ability to diagnose and treat biceps injury has improved. The long head of the biceps functions as an important secondary stabilizer of the glenohumeral joint.[28] However, biceps tendon instability, chronic degeneration, and/or tearing may cause significant shoulder discomfort and dysfunction. Consequently, its value becomes overshadowed. In these situations, biceps tenodesis has been shown to decrease shoulder pain while preserving elbow function.[3,4,8]

Biceps tenodesis may be indicated when the long head of the biceps tendon becomes degenerated more than 25% to 50%.[1] However, recalcitrant cases of tendinitis with normal-appearing tendons can also be treated successfully with a biceps tenodesis.

Instability is a less frequent problem, but can be very symptomatic and can result in unwanted damage to the

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rotator cuff when left untreated. Long head of the biceps tenodesis is indicated when symptoms result from biceps tendon instability or, more importantly, when the rotator cuff may be damaged by the unstable tendon.[1]

Several treatment options have been described that range from benign neglect to tenotomy and/or tenodesis of the biceps tendon. There is still controversy as to which technique is superior. Tenotomy may actually lead to relief of shoulder pain, but can be associated with a cosmetic deformity and mild weakness of elbow supination or flexion.[11] Moreover, in some individuals, painful biceps muscle-belly cramping may develop. Biceps tenodesis before an impending rupture can prevent these undesirable side effects.

Many biceps tenodesis techniques have been described. Some of these procedures rely on bone fixation, including the keyhole[9,21] or interference-screw[18,29]techniques, while others, such as the percutaneous intra-articular transtendon (PITT) technique,[30] rely on soft tissue fixation. Furthermore, there are other methods that include the rotator cuff in the tenodesis.[7] Lastly, hybrid systems have also been described in which suture anchors are used.[10]

Although many of these procedures are worthwhile and are in use today, there has been little information published on the biomechanical strength of the various biceps tenodesis techniques.[13,15,20,26,32] Prior studies have concentrated on the interference-screw and suture-anchor techniques that may be performed either arthroscopically or open.[20,26,27]

However, to our knowledge, no previous study has compared the aforementioned techniques with techniques that rely on soft tissue fixation.

The aim of this study was to evaluate the biomechanical properties of a soft tissue and a hybrid arthroscopic biceps tenodesis—the PITT and the suture-anchor techniques.

The main hypothesis was that the soft tissue procedure would have similar biomechanical properties, including strength and stiffness, as the suture-anchor technique.

MATERIAL AND METHODS

Fifteen fresh-frozen cadaveric humeri were studied. The mean age of the specimens was 50 ± 6 years (range, 42-61 years). Each specimen was thawed at room temperature 24 hours before the procedure. Each shoulder was dissected leaving the isolated biceps tendon intact as a free graft—the tendon was cut from its attachment to the superior labrum and the distal part where it turns into muscle—to be attached to the materials testing machine. In all the specimens, the biceps tendon was inspected and none of them evidenced any type of pathologic abnormalities. The cuff, the transverse ligament, and part of the soft tissue around them were preserved.

Cadaveric specimens were randomized to 2 arthroscopic biceps tenodesis procedures: the suture-anchor[10] (n = 7) and the PITT techniques[30] (n = 8). Surgery was performed in an open fashion simulating the arthroscopic technique.

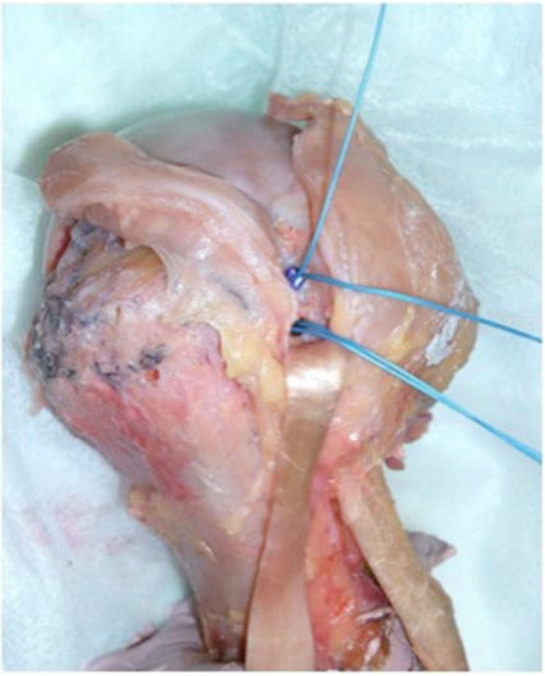

Figure 1. Suture-anchor technique showing the placement of 2 anchors 6 mm apart before passing through the tendon with an all-inside suture technique.

Double-Anchor Technique

This technique consisted of implanting 2 bioresorbable suture anchors (Figure 1) (AnchorSew, USS [United States Surgical] Sports Medicine, North Haven, Connecticut) in the bicipital groove, 6 mm apart, after opening the transverse ligament. Each anchor was loaded with a No. 2 braided nonabsorbable polyester suture (TiCron or Surgidac, United States Surgical, Norwalk, Connecticut) with a needle at the end. Each end of the suture was passed through the biceps tendon with 10 mm of separation in an all-inside fashion. This was done by using the Arthrosew device (USS Sports Medicine), which allows the needle to pass at the end of the suture from 1 side to the other of the tendon. One limb of the first suture, the No. 2 TiCron, was passed posterior/superior, whereas the other limb was passed anterior/inferior. The placement of the second suture, the No. 2 Surgidac, was reversed to form a criss-cross pattern over the tendon. Both sutures were tied down using the sliding Nicky's knot attaching the tendon to the bicipital groove.

The PITT Technique

An 18-gauge spinal needle was used to pierce the transverse ligament and the biceps tendon in an outside-in fashion (Figure 2A). A second needle was placed, in the same fashion, 10 mm distal to the first. The needles pierced the biceps tendon with the first posterior/superior and the second anterior/inferior. Then, a 0 polydioxanone (PDS)

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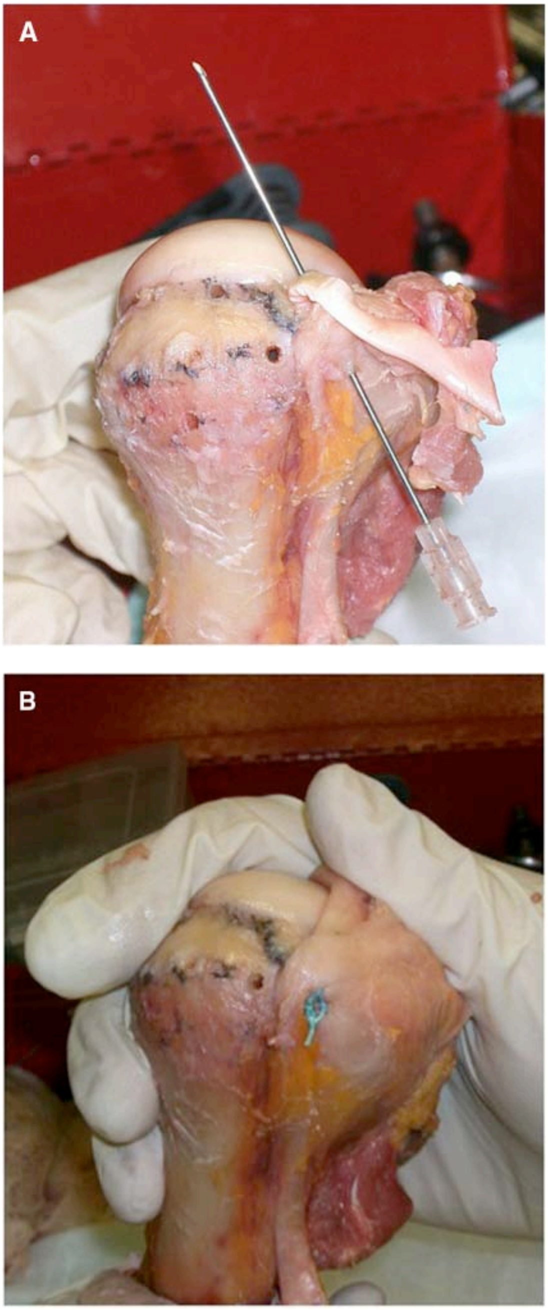

Figure 2. A, PITT technique: spinal needle passing through the transverse ligament and biceps tendon. Two spinal needles were used to pass 2 strands of polydioxanone suture to shuttle a single braided nonabsorbable suture. B, final appearance: a criss-cross pattern with the Nicky's knots over the transverse ligament at the bursal side.

monofilament suture (Ethicon Inc, Johnson & Johnson, Somerville, New Jersey) was threaded through each needle. Both sutures were withdrawn, allowing a single No. 2 braided nonabsorbable polyester suture (TiCron, United States Surgical) to be shuttled back, resulting in the biceps tendon being captured with a mattress-type suture whose loop end was on the articular aspect of the biceps tendon.

The technique was repeated, but the needle placement was reversed to allow for the mattress loop to cross the previous suture in a locking pattern. This time, a different No. 2 braided nonabsorbable polyester suture was used (Surgidac, United States Surgical). The sliding Nicky's knot was used to secure both sutures in the same fashion as the double-anchor technique (Figure 2B); with the only difference being that the biceps tendon was attached to the transverse ligament, instead of to the bone.

Biomechanical Testing

For biomechanical testing of the construct, each humeral shaft was embedded into epoxy putty and held with a specially designed clamp placed on the base of the testing machine (Adelaide Testing Machines, Model TTS-25 Series, Toronto, Ontario, Canada). The distal part of biceps tendon was attached to the materials testing machine by way of a sinusoidal clamp. The worst-case scenario testing protocol was performed by applying the force in line with the tendon and the shaft (Figure 3). During testing, the tissue was kept moist with saline and room temperature was kept at 22ºC.

An initial preload of 5 N was applied to pretension the tendon. A load to failure protocol was then performed at a displacement rate of 1.25 mm/s.

The structural properties of the repaired tendon including ultimate load (N) and stiffness (N/mm) were derived from the load-elongation curve. The mode of failure was also recorded. During the test, no major slippages of test specimens from the clamp were observed.

Statistical Analysis

Analysis of normality was performed on both main variables using the Shapiro-Wilk tests. Once the Gaussian behavior of both variables was assured, both techniques were compared with the parametric Student *t* test with significance set at $P < .05$ (SPSS version 14, SPSS Inc, Chicago, Illinois). The data were presented as means ± standard deviations.

RESULTS

Both repairs demonstrated typical load-displacement curves with an initial toe region followed by a linear increase in load with respect to displacement until failure occurred. Once the construct failed, displacement continued increasing without any increment in load (Figure 4).

The suture-anchor and PITT techniques had ultimate loads of 175.4 ± 40.4 N and 142.7 ± 30.9 N, respectively, with no significant differences between them ($P = .10$) (Figure 5). Stiffness, which is determined by the slope of the load-elongation curve, gives information about the internal properties of the surgical construct. This was 15.9 ± 8.4 N/mm for the suture-anchor technique and 13.3 ± 3 N/mm for the PITT technique, with no statistical difference between techniques ($P = .36$) (Figure 5).

As the type of failure was recorded, all of the surgical constructs, suture anchor and PITT, failed at the tendon

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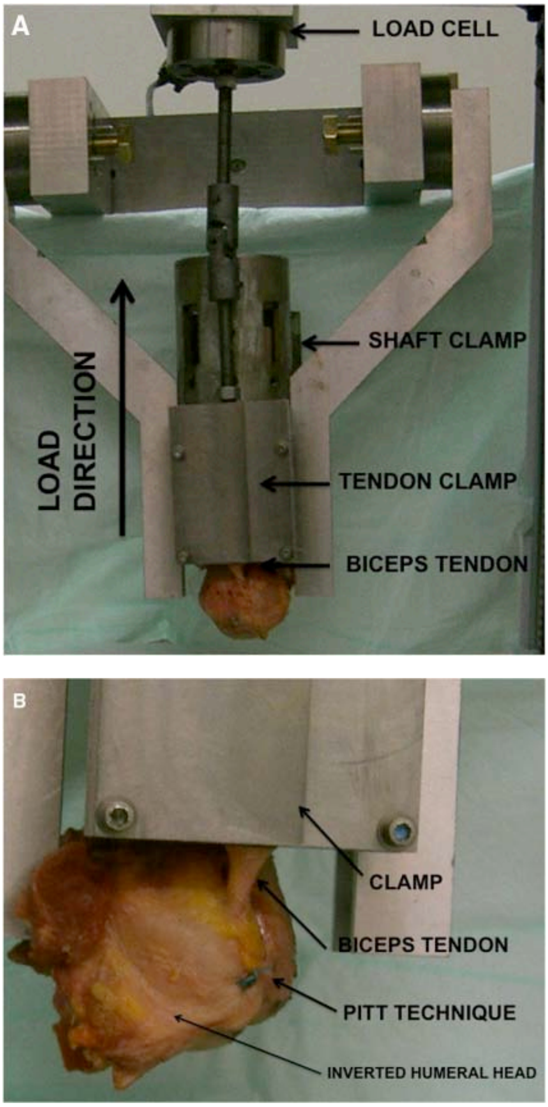

Figure 3. A, experimental testing setup after the percutaneous intra-articular transtendon (PITT) technique for biceps tenodesis. The tendon is pulled parallel to the shaft of the humerus, resembling the worst-case scenario. Note that the construct is in an inverted position. B, close-up of the construct.

site by pulling-out with the sutures through the substance of the tendon (Figure 6).

DISCUSSION

Over the past 10 years, there has been increasing interest in biceps injury and treatment. Biceps tenodesis was traditionally performed using an open "keyhole" technique,[9] in which the long head of the biceps was fixed into a slot fashioned in the intertubercular groove. The technique has fallen out of favor due to the risk of postoperative proximal humeral fractures stemming from the keyhole serving as a stress riser.[2,3,31]

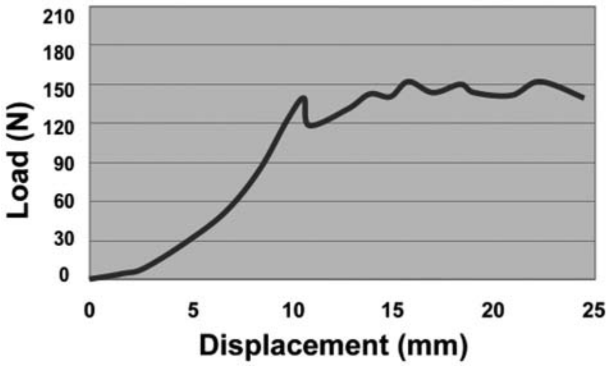

Figure 4. Load-elongation curve, showing a constant increase in load and displacement until failure occurred where only displacement increases. Ultimate load is the higher point of load, and stiffness is the slope of the curve.

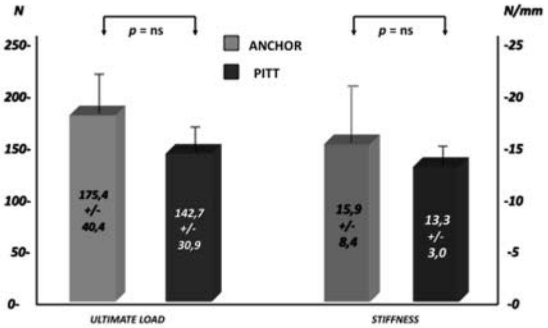

Figure 5. The suture-anchor (SA) and percutaneous intra-articular transtendon (PITT) techniques had ultimate loads of 175.4 ± 40.4 N and 142.7 ± 30.9 N with no significant differences between them ($P > .05$). Stiffness was 15.9 ± 8.4 N/mm for the SA technique and 13.3 ± 3 N/mm for the PITT technique, with no statistical difference between techniques ($P > .05$).

With the introduction of arthroscopy in shoulder surgery, we have a better understanding of the normal and pathologic appearance and the role of the biceps. The clinical results of arthroscopic biceps tenodesis are generally satisfactory. It is an efficacious procedure that relieves pain and prevents deformity, with the added benefit of strength preservation at the elbow.[4,7,24]

A number of arthroscopic techniques for biceps tenodesis have been described that differ in the type of fixation and hardware required. These procedures were suited to the increasing arthroscopic skills of different shoulder surgeons. The type of fixation varies from bony[4,5,14] to soft tissue[30] attachment of the long head of the biceps stump, including some hybrid fixation, such as the suture-anchor technique[6,10] or the use of the biceps as a graft to be included in rotator cuff repairs.[7]

The arthroscopic interference screw procedure was the first to be described. It is a solid technique with the added benefit of a large clinical experience. On the other hand, some surgeons prefer the suture-anchor technique to the interference screw, advocating that a higher risk of

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Figure 6. Type of failure of suture-anchor (SA) and percutaneous intra-articular transtendon (PITT) biceps tenodesis techniques. Note the pullout of the suture through the substance of the tendon.

fracture exists along with the need of bigger incisions. Moreover, there exists the possibility of nerve injury[17,27] and hardware complications such as screw reaction, tenosynovitis, and pain.[20]

In the mid-1990s, Rodosky et al[28] introduced a simple all-arthroscopic soft tissue technique for long head of the biceps tenodesis, called the percutaneous intra-articular transtendon (PITT) technique.[30] Since then, soft tissue techniques have become more popular and have demonstrated clinical benefits.[6-8,19,23] In addition, those surgeons who prefer the PITT technique[19,23] as their first choice favor the suture-anchor technique as their second choice for tenodesis when they face lack of soft tissue to attach the biceps stump.[23]

For all of the above-mentioned reasons, along with the lack of knowledge on the biomechanical properties of soft tissue tenodesis techniques, the PITT and suture-anchor techniques were chosen for the study.

The ultimate load of the interference screw has been widely studied in the literature for biceps tenodesis. Wolf et al[32] reported the superiority of the bioabsorbable interference screw over tenotomy in terms of load failure and migration, showing forces around 310 N in a human cadaveric model. When comparing bioabsorbable and metallic interference screws, Jayamoorthy et al[13] showed ultimate loads of 210 ± 6 N and 234 ± 6 N, respectively, with no statistical differences between them.

Moreover, the comparison of interference screws and suture anchors has been shown to be erratic. Although some studies have found no statistical differences in a human model (242 ± 5 N vs 164 ± 4 N),[20] as well as in a sheep model (243 ±7 N vs 129 ± 2 N),[26] others have stated the superiority of the interference over suture anchors. with cyclic loading, such as Golish et al[12] (169 ± 5 N vs 68 ± 3 N) in a human model and Kusma et al[15] in a porcine model with the flexor tendon acting as the biceps (480 ± 1 N vs 287 ± 3 N). Moreover, Richards and Burkhart[27] obtained significant superior ultimate loads for the interference screw over suture anchors (235 ± 5 N vs135 ± 4 N), using the worst-case scenario testing protocol in a human model.

Although there is controversy in the biomechanical studies about the ultimate load comparing the interference screw and suture anchors, when both techniques are compared in the clinical setting, there is no difference between them in terms of pain, shoulder scores, and failure of fixation.[22]

In our study, higher mean ultimate loads were achieved for the suture anchor (175 ± 4 N) compared with the other studies referenced in the literature. This difference could be attributed to the type of failure, thread used through the eyelet, and/or bone density of the specimens concerning the type of anchor. Furthermore, it could be due to the different type of biomechanical testing protocols and the various speeds used in them.

Because of the use of the worst-case scenario in the testing protocol, the biceps stump in the PITT technique was attached only to the transverse ligament. However, in clinical conditions, the biceps stump might be also attached to the rotator interval and part of the rotator cuff, depending on the surgeon preferences. That should be taken into consideration because, in those cases, the strength of the construct might well be higher.

Stiffness gives information about the internal properties of the construct relating to load and displacement. There is a single study where this variable has been calculated comparing the interference screw and the suture anchor.[12] The authors achieved stiffness of 34 ± 9 N/mm for the interference screw and 19 ± 1 N/mm for the suture anchor, showing the superiority of the interference screw to be statistically significant. Nevertheless, deflection or displacement have also been described in 2 other studies, finding no differences between the 2 techniques.[15,20]

In our study, we have found a stiffness of 15 ± 8 N/mm for the suture-anchor technique and 13 ± 3 N/mm for the PITT technique, with no statistical differences between them. Both stiffness measures are lower than the ones obtained by Golish et al.[12] This issue could be due to the difference in the testing protocols as well as to the length and the quality of the tendon. Moreover, it could be attributed to the different types of anchors, sutures used in them, and construct configuration.

As far as we know, this is the first study to determine the biomechanical properties of any soft tissue tenodesis construct commonly in use.[6-8,23] In our opinion, these results could be of help as a reference for subsequent studies and in clinical practice.

In all the studies describing the mode of failure of the different biceps tenodesis techniques, tendon slippage is the most frequent for the interference screw,[13,20,25,26,32] although fracture of the humerus[27] or the scapula[32] have been described. In addition, suture anchors most frequently failed by breakage of the eyelet, suture rupture, or anchor pullout. Conversely, in our study, the suture-anchor and the PITT constructs failed at the tendon site.

If a closer look is taken at the load-elongation curve, there is a point above which there is only an increase in displacement without increase in load. Moreover, when the

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type of failure is taken into account, this trend in the curve of load-displacement indicates that the sutures were pulling out or tearing through the substance of the biceps in both techniques (Figure 6).

In our opinion, considering these findings, the most important factor for initial strength of these 2 types of tenodesis is not dependent on the attachment site but rather on the quality of the biceps tendon, with this suture configuration. Noteworthy is that the interference screw may not be as dependent on the quality of the tendon as the soft tissue techniques.

To avoid the possible interaction of shoulder dominance, we decided to randomize the specimens instead of pairing them.

If cyclic testing had been used, it could have provided a better idea of how both techniques could have held the daily use and accelerated rehabilitation. However, the worst-case scenario was set by pulling the tendon in line with the construct and parallel to the shaft of the humerus (Figure 3) to assess the lesser forces needed for the ultimate strength and stiffness.

In term of forces, the biceps tendon ranges from 75 N to support the weight of the forearm against gravity up to 300 N if a 20-N weight is held in the hand, depending on the activities and testing method.[13,16] Considering that both techniques showed ultimate load failures around 150 N, absolute immobilization might not be needed and passive and light active movements could be permitted in the early postoperative period.

As observed in the results, we found no significant differences between the PITT and the suture-anchor techniques, although both showed strength and stiffness that fell in the range of other studies.[13,20,26,32] We acknowledge the possibility that the study may be underpowered. However, cadaveric studies are limited by practical considerations by their very nature in terms of numbers. In addition, sample size was chosen according to other biomechanical studies in biceps tenodesis[13,20,26,27] and based on specimen availability.

Although there is a trend toward the superiority of the suture-anchor technique, the measured differences are not considered to be clinically significant given that the failure loads are well above the estimated in vivo loads of 75 N.[16]

Other possible limitations of biomechanical studies in which cadaveric specimens are used are that they do not resemble the healing process or simulate the effect of postoperative immobilization. However, they resemble time 0 of the postoperative period.

Furthermore, all the tendons that were included in the study were normal in appearance with no evidence of chronic degenerative changes, which are usually the main cause of rupture and indication for tenodesis.

Lastly, the fact that we did not assess bone density and/or pair the specimens for this risk factor could be an issue to be considered, mainly for the suture-anchor technique. However, we found no anchor pullout failures.

In light of our results, the PITT technique could be considered as strong as the other open and arthroscopic techniques, except for the interference screws, avoiding the complications related to open surgery, the use of hardware, and the influence of bony structural properties.

In addition, this soft tissue tenodesis avoids the cost of implants without interfering with MRI or CT scans for second-look surgery. These are factors that should be taken into account when deciding which technique the surgeon is going to perform, considering that biceps tenodesis is not usually a single procedure in arthroscopic shoulder surgery.

CONCLUSION

The suture-anchor and PITT techniques exhibited satisfactory initial strength with no statistical difference between the 2 groups.

These findings, along with the consistent pullout of the suture through the tendon during failure, suggest that the most important factor for initial strength is not the attachment site but the quality of the biceps tendon. This may be important when considering postoperative immobilization.

With no differences in initial strength, a soft tissue tenodesis is a more cost-effective operation without interfering with MRI or CT scans for second-look surgeries.

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