

A Comparative Biomechanical Analysis of 2 Double-Row, Distal Triceps Tendon Repairs

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Background: Triceps tendon ruptures are rare orthopaedic injuries that almost always require surgical repair. This study tests the biomechanical properties of an original anchorless double-row triceps repair against a previously reported knotless double-row repair.

Hypothesis: The anchorless double-row triceps repair technique will yield similar biomechanical properties when compared with the knotless double-row repair technique.

Study Design: Controlled laboratory study.

Methods: Eighteen cadaver arms were randomized into 2 groups. One group received the anchorless repair and the other received the knotless anchor repair. A materials testing system (MTS) machine was used to cycle the repaired arms from 0° to 90° with a 2.5-pound weight for 1500 cycles at 0.25 Hz. Real-time displacement of the tendon was measured during cycling using a probe. Load to failure was performed after completion of cyclic loading.

Results: The mean displacement with the anchorless technique was 0.77 mm (SD, 0.25 mm) at 0° (full elbow extension) and 0.76 mm (SD, 0.38 mm) at 90° (elbow flexion). The mean displacement with the anchored technique was 0.83 mm (SD, 0.57 mm) at 0° and 1.01 mm (SD, 0.62 mm) at 90°. There was no statistically significant difference for tendon displacement at 0° ($P = .75$) or 90° ($P = .31$). The mean load to failure with the anchorless technique was 618.9 N (SD, 185.6 N), while it was 560.5 N (SD, 154.1 N) with the anchored technique, again with no statistically significant difference ($P = .28$).

Conclusion: Our anchorless double-row triceps repair technique yields comparable biomechanical properties to previously described double-row triceps tendon repair techniques, with the added benefit of avoiding the cost of suture anchors.

Clinical Relevance: This anchorless double-row triceps tendon repair can be considered as an acceptable alternative to a knotless anchor repair for triceps tendon ruptures.

Keywords: elbow; triceps; tendon; triceps repair; biomechanical

Triceps tendon ruptures are rare orthopaedic injuries, encompassing approximately 1% of all observed upper extremity tendon injuries. These ruptures typically result

from a fall on an outstretched arm or when an excessive eccentric load is applied during elbow extension in activities such as weightlifting.^{1,4,5,13,14,16} Both anabolic steroid use and local steroid injections are reported risk factors for triceps rupture.^{5,12-14} Furthermore, systemic diseases associated with pathologic bone metabolism such as renal osteodystrophy and insulin-dependent diabetes mellitus have been implicated as risk factors for tendon rupture.^{3,8,14} Patients with a triceps tear will lose elbow extension strength,¹⁰ diminishing their ability to perform daily tasks such as opening doors. Fortunately, acute complete distal triceps tendon ruptures are responsive to repair if operated upon in the acute phase after injury.⁵

Over the past 2 decades, several studies have addressed evolving surgical repair techniques for complete triceps tendon ruptures.^{3,5-8,11,13} While cadaver studies have favored the biomechanical properties resulting from certain techniques, particularly those that provide the greatest coverage of the muscle's original dome-shaped bony

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footprint on the olecranon,¹⁶ the optimal repair technique for triceps ruptures continues to be debated.⁸

Triceps tendon repair was traditionally managed by reattaching the tendon to its insertion on the olecranon with large nonabsorbable sutures weaved through the bicruciate bone tunnels.^{9,15} While the majority of such repairs heal without incident, the standard transosseous bicruciate bone-tunnel technique has been shown to have a rerupture incidence of up to 21%, as well as other issues such as elbow irritation from palpable knots.^{13,15} The rapid advancement of suture anchor technology has spurred the development of new triceps repair techniques using suture anchors in place of bone tunnels to reattach the tendon to its entire footprint.^{2,16}

Paci et al¹³ recently described a new hybrid knotless technique that employs both bone tunnels and a single suture anchor. They feel that this repair offers both biomechanical superiority and low-profile fixation. Paci et al¹³ compared this hybrid knotless and the transosseous bicruciate techniques in cadavers and demonstrated a high level of biomechanical strength with the knotless technique in cyclic loading and load-to-failure testing.⁵

The goal of this study was to assess biomechanically the properties of an anchorless double-row triceps tendon repair technique using cadaver models against the hybrid, knotless technique described in Paci et al¹³ in an attempt to determine whether there is any difference in cyclic loading and ultimate load to failure resulting from the 2 repair techniques.

METHODS

Triceps Repair Protocol

We obtained 9 matched-pair cadaver elbows (18 total; mean age, 80.44 ± 5.94 years) from our institution's cadaver donor program. None of the cadavers had any prior upper extremity orthopaedic procedures or known elbow pathology.

We created a simulated distal triceps tendon tear in each specimen by using a scalpel to incise and peel back the triceps tendon from its anatomic bony footprint. Using a random number generator, we randomized each pair of elbows to receive the anchorless double-row repair (senior author's [M.J.D.] technique) or the hybrid knotless (Paci et al¹³) double-row repair, using No. 2 Ethibond (Ethicon) suture for both techniques. This resulted in 9 elbows (5 right and 4 left) randomized to the new technique and 9 (4 right and 5 left) to the Paci repair technique.

All triceps tears were created and repaired by 2 orthopaedic surgeons (1 attending surgeon and 1 second-year resident). Both surgeons practiced their respective technique on sawbones and cadaver specimens in at least 6 trials each prior to creating the actual test specimens. The attending surgeon performed the anchorless repairs and the resident performed the hybrid repair. Elbow samples were held in a cooling freezer per the donor cadaver program protocol until biomechanical testing could be carried out. The triceps specimens were thawed at room temperature prior to testing.

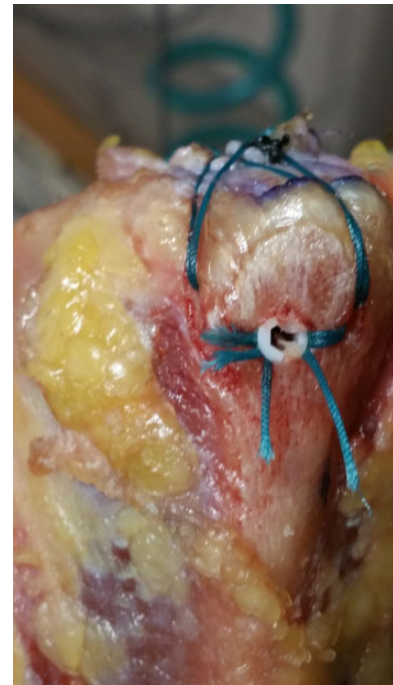


Figure 1. Repair technique of Paci et al.¹³

Triceps Repair Techniques

The hybrid knotless triceps repair technique was performed per the technique described by Paci et al¹³ (Figure 1). The description of the anchorless double-row technique is below.

Two sets of bicruciate tunnels were drilled in the olecranon process using a 2-mm drill bit. One set was dorsal (superficial) and the other set was volar (deep). The tunnels were drilled from proximal to distal. Starting at the volar corners of the footprint, the deep tunnels were drilled in a crossing pattern (medial to lateral and vice versa), oriented so that the tunnel's exit was 1.5 to 2.5 cm distal to the tip of the olecranon and 8 to 10 mm to the side of the dorsal ulnar ridge in the space created where the muscle attachments were elevated. The superficial (dorsal) tunnels were then drilled in a similar crossing fashion starting from the dorsal corners of the footprint. Their orientation aimed to have their distal holes exit the side of the dorsal ulnar ridge 10 to 12 mm proximal to the deep tunnels, again in the bony area exposed under the elevated muscle masses.

Two sets of running Krackow No. 2 Ethibond sutures were placed in the distal triceps so that 4 free ends exited on the deep surface of the triceps, corresponding to the outer points of footprint contact on the olecranon (Figure 2).

The volar Krackow sutures and 1 free suture were passed through each volar drill tunnel (Figure 3).

The free sutures (those unattached to the triceps) were then crossed and passed retrograde through the superficial tunnels, exiting at the dorsal corners of the footprint (Figure 4).

The dorsal Krackow sutures were then passed through the dorsal set of bone tunnels on the triceps footprint. There

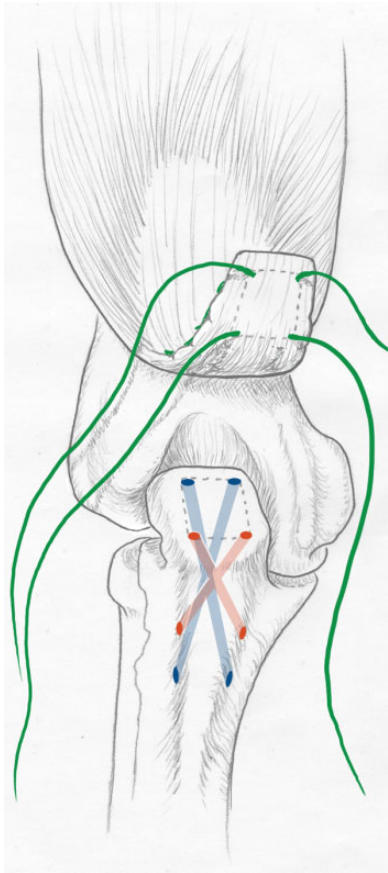


Figure 2. Krackow sutures are placed through the distal triceps tendon. Two sets of crossing tunnels are drilled, 1 dorsal (superficial) and 1 volar (deep). Both are drilled from proximal to distal.

should be 4 free suture ends exiting the olecranon proximally via the holes in each corner of the footprint (Figure 5).

Using a free needle, these 4 suture ends were then passed through the triceps tendon from deep to superficial just adjacent to the Krackow sutures that share the same bone tunnel. The points at which the sutures were passed through the tendon correspond to the 4 corners of the triceps footprint (Figure 6).

The arm was held in extension, and the distal sutures were tied over bone tunnels, ensuring the knots were positioned along the medial and lateral ulna instead of the dorsal ridge of the ulna. This allows for the knots to be covered by muscle closure. The proximal “compression” sutures were tied in a crossing fashion (creating an “X”) over the distal triceps tendon (Figure 7).

Biomechanical Testing Protocol

Humerus. After the appropriate repair had been performed for each sample, the triceps muscle belly was detached from the humerus, and a polypropylene strap was folded around the cut proximal end of the triceps muscle belly; a No. 1 Ethibond suture was used to secure it in place.

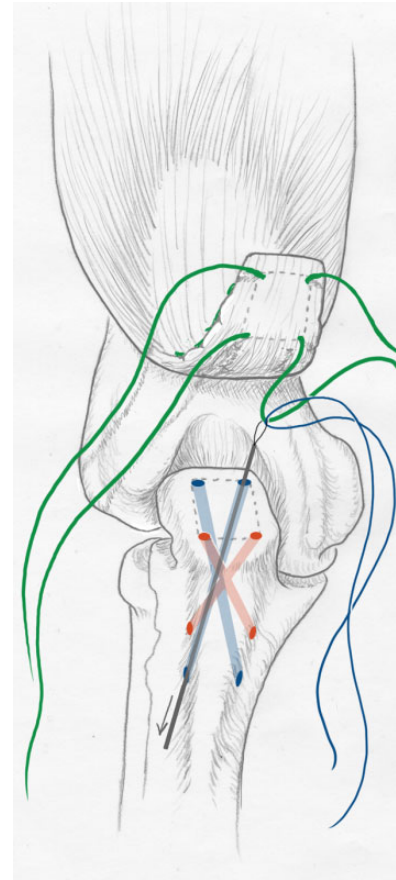


Figure 3. The volar Krackow sutures, and 1 free suture, are passed through each volar drill tunnel.

A carabiner was placed through the looped strap formed at the proximal end of the muscle. The proximal end of the humerus was pinned inside a vertically oriented polyvinyl chloride pipe that was mounted to the materials testing system (MTS) machine using 4.5-mm Steinmann pins at multiple levels and orientations. The angle of orientation of the triceps in relation to the humerus was approximately 20°.

Ulna. A threaded rod was bolted into the intramedullary canal of the ulna, and a 2-pound weight was placed onto the threaded rod and positioned 8 inches from the proximal tip of the olecranon, secured in place with a bolt on either side. This is in accordance with the study by Yeh et al.¹⁶

A linear displacement transducer (Microstrain) was placed at the bone-tendon interface of the distal triceps tendon and held in place using sutures that did not compromise the repair. The proximal end of the transducer was secured to a suture needle at the proximal aspect of the tendon. This method elevated the transducer off the tendon to prevent impingement during cyclic loading.

One end of the cable was affixed to the carabiner attached to the triceps and the other end to the displacement arm of the MTS machine. The cable ran through a pulley positioned directly under the displacement arm (Figure 8).

The construct was preconditioned by cycling the elbow through a range of motion from 0° to 90° 10 times. Probe attachments were checked and confirmed to be unaltered

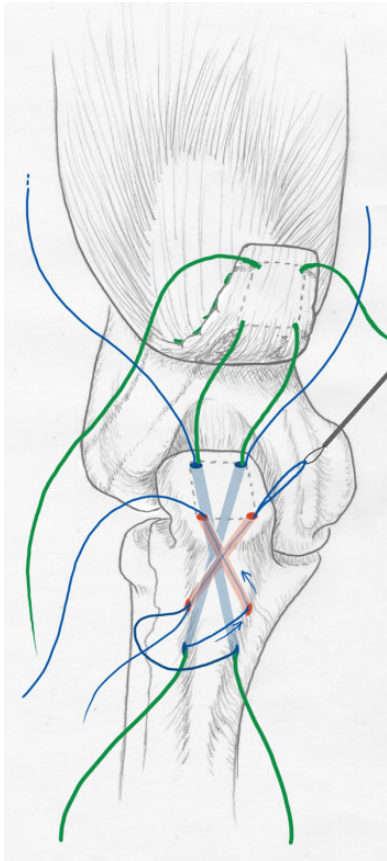


Figure 4. The free sutures are passed through different tunnels. The suture exiting the distal lateral drill hole is passed back through the proximal medial exit hole. The suture exiting the distal medial drill hole is passed back through the proximal lateral exit hole.

prior to testing. The linear displacement readings were noted on the probe before performing the testing protocol.

Each construct was cycled from 0° to 90° 1500 times at 0.25 Hz. Linear displacement was measured at the insertion site throughout cycling 3 times: after 500, 1000, and 1500 cycles. The transducer was subsequently removed prior to load-to-failure testing.

Load-to-failure testing was performed using a displacement technique at 120 mm/min with the elbow locked in a fixed position at 90°. This was accomplished by securing a zip tie from 1 of the Steinmann pins to the ulna and radius. Each specimen was examined for mechanism of failure after load-to-failure testing.

The triceps, suture, and all hardware except the anchors were removed from the elbow specimens and were subsequently disarticulated and inspected for intra-articular drill penetration. Kirschner wires were placed through the deep drill holes in each ulna, and a mini C-arm was utilized to obtain a lateral view of each specimen. Films were digitized. The distance between the nearest K-wire and the ulnar cartilage surface was measured.

Statistical analysis was conducted with paired-sample Student *t* tests using SPSS statistical software (IBM Corp).

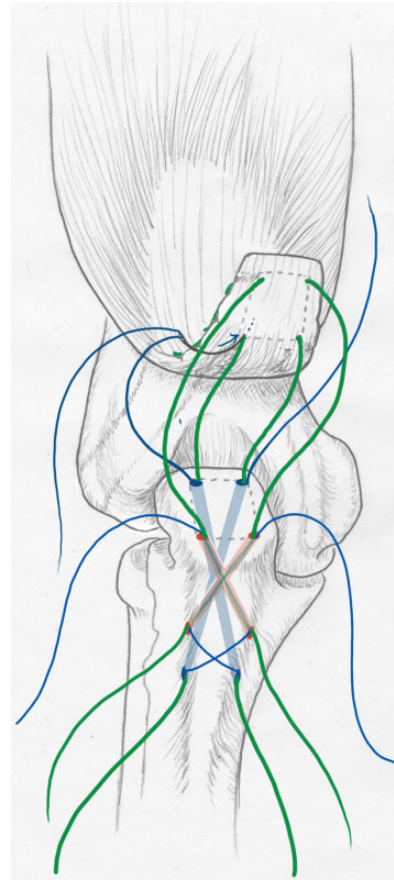


Figure 5. Four free suture ends exit the olecranon proximally via the holes in each corner of the footprint.

Because statistical power was likely to be low, Cohen effect sizes were calculated to determine whether a significant difference could be observed with larger sample sizes.

RESULTS

All repairs performed on our cadaver specimens were subjected to cyclic loading. After the 1500 cycles from 0° to 90°, the mean displacement of the anchorless double-row repair with the elbow at 0° (full elbow extension) was 0.77 mm (SD, 0.25 mm). In contrast, the mean displacement for the Paci technique at 0° was 0.83 mm (SD, 0.57 mm). There was no statistically significant difference between the techniques for tendon displacement at 0° ($P = .75$, paired *t* test) (Table 1). Additionally, Cohen's effect size value ($d = 0.146$) suggested there is likely no significant difference even in larger samples.

The mean displacement of the anchorless double-row repair at 90° (elbow flexion) was 0.76 mm (SD, 0.38 mm). The mean displacement for the Paci technique at 90° was 1.01 mm (SD, 0.62 mm). There was no statistically significant difference between techniques for tendon displacement at 90° ($P = .31$, paired *t* test) (Table 2). The Cohen effect size value ($d = 0.37$) suggested that a significant difference may be observed with larger sample sizes.

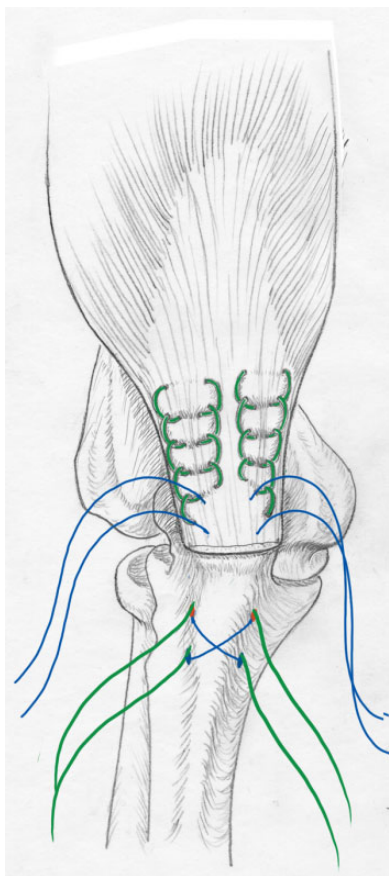


Figure 6. A free needle is used to pass each suture end through the triceps tendon from deep to superficial. The points at which the sutures are passed represent the triceps footprint.

No repairs in either the anchorless double-row or Paci cohorts failed during cyclic loading. Subsequently, all were subjected to load-to-failure analysis. The mean load to failure for the 9 anchorless double-row repairs was 618.9 N (SD, 185.6 N). The mean load to failure for the 9 Paci repairs was 560.5 N (SD, 154.1 N). The difference in load to failure between the 2 cohorts was not statistically significant ($P = .28$, paired t test) (Table 3). The Cohen effect size value ($d = 0.40$) suggested that a significant difference may be observed with larger sample sizes. With regard to method of failure, 16 repairs failed at the tendon-suture interface, and 2 Paci repairs failed because of bone tunnel cut-out.

Measurements taken from the digitized images with the Kirschner wires in place demonstrated a mean distance from the joint of 3.74 mm (SD, 0.92 mm). No intra-articular penetration was seen with visual or radiographic inspection.

DISCUSSION

The results of this study support the conclusion that the biomechanical strength of the anchorless double-row

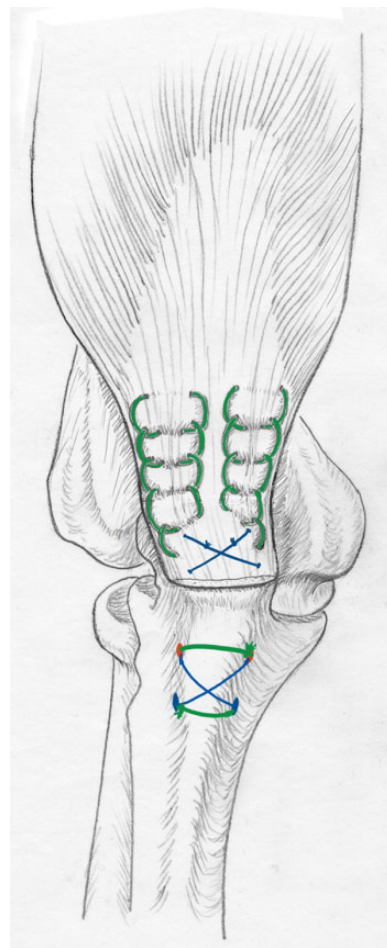


Figure 7. The distal sutures are tied across the bone bridges. The knots should be placed over the medial or lateral ulna. The proximal sutures are tied to create an “X” pattern over the tendon.



Figure 8. Biomechanical setup.

distal triceps repair is comparable to the knotless, hybrid double-row repair described in Paci et al.¹³ Although sample sizes were low in this study, the Cohen effect size suggests a significant difference may be seen with larger sample sizes, which could be evaluated in future studies.

TABLE 1
Mean Displacement After 1500 Cycles at 0°, mm^a

Technique	Mean	SD
Paci	0.83	0.57
Anchorless double-row	0.77	0.25

^aThese values are not statistically significant, $P = .75$.

TABLE 2
Mean Displacement After 1500 Cycles at 90°, mm

Technique	Mean	SD
Paci	1.01	0.62
Anchorless double-row	0.76	0.38

^aThese values are not statistically significant, $P = .31$.

TABLE 3
Mean Load to Failure^a

Technique	Mean	SD
Paci	560.5 N	154.1
Anchorless double-row	618.9 N	185.6

^aThese values are not statistically significant, $P = .28$.

With both techniques exhibiting similar repair strength, there may be other theoretical advantages to the anchorless double-row technique. Other techniques that employ anchor placement require the drilling of an anchor toward the joint space, carrying with them a potential risk of plunging into the joint space if a drill stop is not used. This anchorless technique avoids drilling directly toward the ulnohumeral joint space, passing instead more tangential through the bone. Our analysis showed that using the current technique, we avoided joint space penetration in all cases. Another advantage of our technique is that it is less expensive in that it does not require costly suture anchors. This anchorless repair utilizes instrumentation that is readily available to the surgical team.

The transosseous bicruciate technique was described by van Riet et al¹⁵ more than a decade ago, published at a time when there was little literature on triceps repair techniques. Although the technique is similar to ours in that it relies on bone tunnels exclusively, our addition of 2 additional tunnels—a row placed more superficially (dorsal) and another row more deeply (volar)—with double-crossing nonabsorbable suture provides more coverage of the triceps footprint. Furthermore, the traditional transosseous bicruciate technique did not fare well compared with suture anchor techniques in biomechanical cadaver studies.¹⁶ Finally, our repair also theoretically decreases the likelihood of the long-term elbow irritation seen in other bone-tunnel repairs,¹³ as we bury the knots under local muscle bellies.

One limitation of this study is that only 1 transducer was used to measure gapping across the repair site. It is therefore possible that either the lateral or medial aspect of the repair experienced more gapping than the other. This could be explored further in future studies. Another limitation of this study was that it compared only 1 alternative to the anchorless technique. Clark et al⁵ demonstrated support for the superiority of the Paci knotless technique (used for comparison in our study) when matched against the transosseous bicruciate technique described by van Riet et al¹⁵ with regard to cyclic displacement and load to failure. Although this comparison was not directly evaluated in the current study, deduction would infer that the anchorless technique is likely superior to the bicruciate transosseous repair given that the difference in strength seen with the anchorless technique and the knotless technique was found to be insignificant in this study. Future experiments with more comparison groups would be helpful in determining how the anchorless double-row repair fares against techniques such as the suture anchor repair described in Bava et al² or the anatomic repair technique described in Yeh et al.¹⁶ Despite a direct comparison, the load-to-failure values observed with the anchorless repair group in this study were comparable to the anatomic repair in the study performed by Yeh et al.¹⁶

A weakness of this study is that a less experienced surgeon performed the Paci repair in all specimens, which may have compromised the repair strength. However, displacement after cyclic loading and load to failure were comparable to the values obtained by Clark et al.⁵ Footprint coverage was not measured in this study. Although the actual footprint coverage was not calculated, our drill holes were positioned in the same locations as those described by Paci et al,¹³ so we would expect similar footprint coverage. This was observed to be the case during testing. Finally, this is a cadaver-based biomechanical study, and it is difficult to extrapolate the clinical significance. The effect of postoperative rehabilitation on the repair is a point of emphasis for future studies.

In conclusion, our study demonstrates that the anchorless double-row triceps repair has comparable biomechanical properties to a previously described double-row triceps tendon repair. Consequently, this repair can be considered an acceptable alternative to a knotless anchor repair for triceps tendon ruptures. The cost savings of avoiding suture anchors, in addition to the equivalent biomechanical properties, may make it a preferable alternative to other described techniques.

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REFERENCES

1. Anzel S, Covey K, Weiner A, Lipscomb P. Disruption of muscles and tendons; an analysis of 1,014 cases. *Surgery*. 1959;45:406-414.

2. Bava E, Barber F, Lund E. Clinical outcome after suture anchor repair for complete traumatic rupture of the distal triceps tendon. *Arthroscopy*. 2012;28:1058-1063.
3. Bennett J, Mehlhoff T. Triceps tendon repair. *J Hand Surg Am*. 2015; 40:1677-1683.
4. Celli A, Arash A, Adams R, Morrey B. Triceps insufficiency following total elbow arthroplasty. *J Bone Joint Surg Am*. 2005;87-A:1957-1964.
5. Clark J, Obopilwe E, Rizzi A, et al. Distal triceps knotless anatomic footprint repair is superior to transosseous cruciate repair: a biomechanical comparison. *Arthroscopy*. 2014;30:1254-1260.
6. Hastings D, Gibson D. Rupture of the triceps tendon in adolescence: case report, with technique of repair. *Can J Surg*. 1964;1(7):67-69.
7. Heikenfeld R, Listringhaus R, Godolias G. Endoscopic repair of tears of the superficial layer of the distal triceps tendon. *Arthroscopy*. 2014; 30:785-789.
8. Kokkalis Z, Mavrogenis A, Spyridonos S, Papagelopoulos P, Weiser R, Sotereanos D. Triceps brachii distal tendon reattachment with a double-row technique. *Orthopedics*. 2013;36:110-116.
9. Kose O, Faruk Kilicaslan O, Guler F, Acar B, Yalcin Yuksel H. Functional outcomes and complications after surgical repair of triceps tendon rupture. *Eur J Orthop Surg Traumatol*. 2015;25: 1131-1139.
10. Keener J, Chafik D, Kim M, Galatz L, Yamaguchi K. Insertional anatomy of the triceps brachii tendon. *J Shoulder Elbow Surg*. 2010;19:399-405.
11. Levy M. Repair of triceps tendon avulsions or ruptures. *J Bone Joint Surg Br*. 1987;69:115.
12. Mair S, Isbell W, Gill T, Schlegel T, Hawkins R. Triceps tendon ruptures in professional football players. *Am J Sports Med*. 2004; 32:431-434.
13. Paci J, Clark J, Rizzi A. Distal triceps knotless anatomic footprint repair: a new technique. *Arthrosc Tech*. 2014;3:e621-e626.
14. Tom J, Kumar N, Cerynik D, Mashru R, Parrella M. Diagnosis and treatment of triceps tendon injuries: a review of the literature. *Clin J Sport Med*. 2014;24:197-204.
15. van Riet R, Morrey B, Ho E, O'Driscoll S. Surgical treatment of distal triceps ruptures. *J Bone Joint Surg Am*. 2003;85-A:1961-1967.
16. Yeh P, Stephens K, Solovyova O, et al. The distal triceps tendon footprint and a biomechanical analysis of 3 repair techniques. *Am J Sports Med*. 2010;38:1025-1033.