Pressure on the Rotator Cuff Repair with Transosseous and Modified Mason-Allen Sutures

Presión en la reparación de manguito rotador con suturas transóseas y Mason-Allen modificado

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Abstract

Objective To compare the average contact pressure curve and the percentage of final residual contact pressure at the tendon-footprint interphase of a transosseous (TO) repair performed with crossover suture or a modified Mason-Allen (MMA) configuration.

Methods Eight lamb shoulders were used to simulate a rotator cuff tear. The pressure was measured with a digital sensor. The baseline pressure was recorded during the application of the cyclic load and at the end of the intervention. Two repairs were compared: 2 crossover TO sutures (CTOs) ($n = 4$) and 2 MMA sutures MMA ($n = 4$), using MaxBraid #2 (Zimmer Biomet, Warsaw, IN, US) sutures. A thousand cycles were performed, with a frequency of 2 Hz and a 30-N load. The Student *t*-test was used, and significance was set at $p < 0.05$.

Results The average contact pressure curve was of 86.01 ± 8.43% for parts repaired with CTO sutures, and of 73.28 ± 12.01% for those repaired with MMA sutures ($p < 0.0004$). The mean residual percentage at the end of cycling was of 71.57% for CTO sutures, and of 51.19% for MMA sutures ($p < 0.05$).

Conclusion The CTO repair shows a higher average contact pressure curve and a higher percentage of final residual contact pressure at the tendon-footprint interphase than the MMA suture repair after standardized cyclic loading, potentially resulting in improved tendon healing.

Level of Evidence Basic Science Study.

Keywords
- rotator cuff
- pressure
- suture
- suture techniques
- tendon injuries
- tendons

Resumen

Objetivo Comparar el promedio de curva de presión de contacto y el porcentaje de presión de contacto residual final en la interfase tendón-huella de una reparación

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transósea (TO) realizada con nudos cruzados y una configuración Mason-Allen modificada (MAM).

Métodos Se utilizaron ocho hombros de cordero para simular una rotura de manguito rotador. Se midió la presión con un sensor digital. Se registró la presión basal durante la aplicación de carga cíclica y al final de la intervención. Se compararon dos reparaciones: dos túneles TOs con nudos cruzados (TOCs) ($n=4$) y dos puntos MAMs ($n=4$) utilizando suturas MaxBraid #2 (Zimmer Biomet, Warsaw, IN, EEUU). Se realizaron mil ciclos, con una frecuencia de 2 Hz y una carga de 30 N. Se utilizó el test de *t* de Student, y se consideraron significativos valores de $p<0{,}05$.

Resultados El promedio de curva de presión de contacto en las piezas que fueron reparadas con suturas TOCs fue de 86,01 ± 8,43%, mientras que con MAM fue de 73,28 ± 12,01% ($p<0{,}0004$). El promedio del porcentaje residual al final del ciclado fue de 71,57% para suturas TOCs y de 51,19% para MAM ($p<0{,}05$).

Conclusión La reparación TOC presenta mayor promedio de curva de presión de contacto y mayor porcentaje de presión de contacto residual final en la interfase tendón-huella que la reparación con sutura MAM luego de carga cíclica estandarizada, lo que podría traducirse en una mejor cicatrización del tendón.

Nivel de Evidencia Estudio de ciencia básica.

Palabras Clave
- manguito de los rotadores
- presión
- sutura
- técnicas de sutura
- traumatismos de los tendones
- tendones

Introduction

Arthroscopic rotator cuff repairs have increased steadily in recent years.[1] Most cases show good to excellent clinical and functional outcomes both in the short and long terms;[2–5] however, re-rupture rates are still considerable, ranging from 11% to 68% in some series, and even 94% in selected studies.[6–8]

Rotator cuff repair surgery seeks to establish a fibrovascular interphase between the tendon and the footprint, which is required for healing and restoration of the fibrocartilaginous insertion (enthesis); this is achieved with a construct that maximizes the pressurized contact between the tendon and the bone while maintaining mechanical resistance against the physiological load.[9] Re-rupture is associated with patient- and repair-related factors (anatomical factors). Patient-related factors include increasing age, larger tear size (compromise of multiple tendons), lower tendon quality, muscle atrophy, fat degeneration (Goutallier classification ≥ 3), tendon retraction, longer evolution time, and comorbidities (smoking, diabetes, hypercholesterolemia, alcoholism, obesity, and hypertension).[7,10] Anatomical, repair-related factors include construct tension, tissue perfusion, micromotion at the tendon-footprint interphase, and the contact pressure and area of the footprint.[11] The underlying principle is that a greater magnitude and distribution of the tendon-to-bone contact area will increase the chance of tendon healing.[12]

Several biomechanical studies on double-row (DR) repair demonstrated an increased resistance to load-related failure, improved contact pressures and areas, and decreased gap formation at the tendon-footprint interphase when compared to the single-row (SR) repair.[5,13] However, the anchors provide low resistance, are prone to loosen in osteoporotic bone, lose optimal contact at the level of the supraspinatus tendon footprint, and result in greater tuberosity osteolysis; in addition, they are associated with difficult revision and increased costs.[14,15] Failure sites can include the tendon, the suture, the bone, or the anchor, as well as the interphases between the bone and the anchor, the anchor and the suture, or the suture and the tendon.[16] This has led to the creation of new types of anchors, such as suture anchors.[17,18]

The transosseous (TO) technique maximizes the contact area of the tendon-footprint interphase,[19] and reduces movement at the tendon-bone interphase.[20] In addition to this mechanical aspect, the TO technique allows the bone side of the lesion to be precisely prepared with no risks or complications, such as anchor removal and/or osteolysis of the greater tuberosity.[21,22]

The TO suture techniques are efficient and reproducible in the arthroscopic repair of rotator cuff tears.[23] In addition, the potential for healing is greater because of the direct contact between the tendon and the bone (with no intervening anchor material) and mesenchymal stem cells from proximal humeral tunnels.[24–26]

In 2009, Burkhart et al.[27] described a mechanism by which increased stress applied to the construct increases resistance to structural failure due to a progressive increase in compressive forces at the tendon footprint, and called it self-reinforcement. The compressive forces created in the footprint increase the resistance to friction between the tendon and the bone, thus reducing the formation of a gap between the two surfaces.

The SR repair with the modified Mason-Allen (MMA) technique according to Habermayer[28–30] is easily performed and provides excellent initial fixation strength, allowing long-lasting osteofibroblastic integration of the reinserted sleeve; in addition, it has reproducible, good to excellent clinical outcomes, with a 25% re-rupture rate, which is consistent with the open repair.[30]

The present study aims to compare the average contact pressure curve and the percentage of final residual contact pressure at the tendon-footprint interphase repaired with a crossover TO (CTO) or MMA suture. Our hypothesis is that the CTO configuration will have a higher average contact pressure curve and a higher percentage of final residual contact pressure at the tendon-footprint interphase.

Materials and Methods

Animal Model

Eight 6-month-old fresh frozen lamb (*Ovis orientalis aries*) shoulders obtained from a local meat processing plant (oyster shoulder cut, Frigorífico Simunovic Ltda., Punta Arenas, Región de Magallanes y Antártica Chilena, Chile) were thawed at room temperature the night before the biomechanical tests (18 hours in total, with fully thawed anatomical parts at room temperature). The infraspinatus tendon was selected because its anatomical and functional characteristics are consistent with those of the human supraspinatus tendon.[31] The specimens were dissected following a standardized technique, removing all soft tissue associated with the humeral shaft, subscapular fossa, and supraspinatus fossa to isolate the infraspinatus muscle and its tendon. No specimen showed rotator cuff changes. Then, the infraspinatus tendon was dissected carefully and fixated to a polypropylene nylon tape using a Krackow-type suture with MaxBraid #2 (Zimmer Biomet, Warsaw, IN, US) to enable muscle and tendon manipulation without tearing them; the tape was clamped to a linear actuator with an intermediate load cell (►**Figure 1**). The parts were irrigated intermittently with saline solution (0.9% NaCl) throughout each test to prevent dehydration of the specimens.

A tailored system generated cyclical tensions at the level of the infraspinatus tendon (►**Figure 2**). The model consisted of three fundamental parts: a modular support with adjustable height, an adjustable support for guidance of the suture system, and a linear actuator with an intermediate load cell. The actuator was programmed to cycle at a 2-Hz frequency and a 30-N load for a total of 1,000 cycles. The contact pressure was recorded every 50 cycles. The humeral shaft was fixated with a metal clamp. Then, the modular support was adjusted to ensure that the tendon was parallel to a vertical line (using a level), generating a tendon traction vector at 0° of abduction and 0° of rotation. (►**Figure 3**).

Rotator Cuff Tear

In each humeral head, the orientation of the greater tuberosity was identified and demarcated with a 1.5 mm Kirschner wire. Next, the tip of the tuberosity was identified, and a full-thickness, full-width tear was made with a #15 scalpel, releasing the entire tendon attachment to the footprint, and then flattening it with a rasp to facilitate the installation of pressure sensors (►**Figure 4**).

Pressure Measurement at the Tendon-footprint Interphase

A Tekscan FlexiForce digital pressure sensor (Tekscan, Inc., Boston, MA, US) was used to measure the pressure at the tendon-footprint interphase. The sensor was positioned between the tendon and the footprint, remaining fixated by the repair performed and covering the total footprint area; it records pressure changes over time and stores these readings in a computer for later analysis. The baseline pressure was recorded at the beginning of the experiment (time 0), during cyclic loading (every 50 cycles), and at the end of the intervention (1,000 cycles).

Repair of Rotator Cuff Tear with Transosseous Sutures and Modified Mason-Allen Suture

A braided, nonabsorbable, polyethylene polymer MaxBraid #2 suture was used for the repair, which is consistent with the suture size most commonly used in arthroscopic shoulder surgery. The TO tunnels were made with a device previously designed by our team and used in other models to generate oblique architecture tunnels (►**Figure 5**).

Two different repairs were performed: 2 CTO tunnels with MaxBraid #2 sutures ($n = 4$) (►**Figure 6a**); and 2 MMA sutures using 2 double-titanium Ti-Screw anchors loaded with MaxBraid #2 ($n = 4$) (►**Figure 6b**).

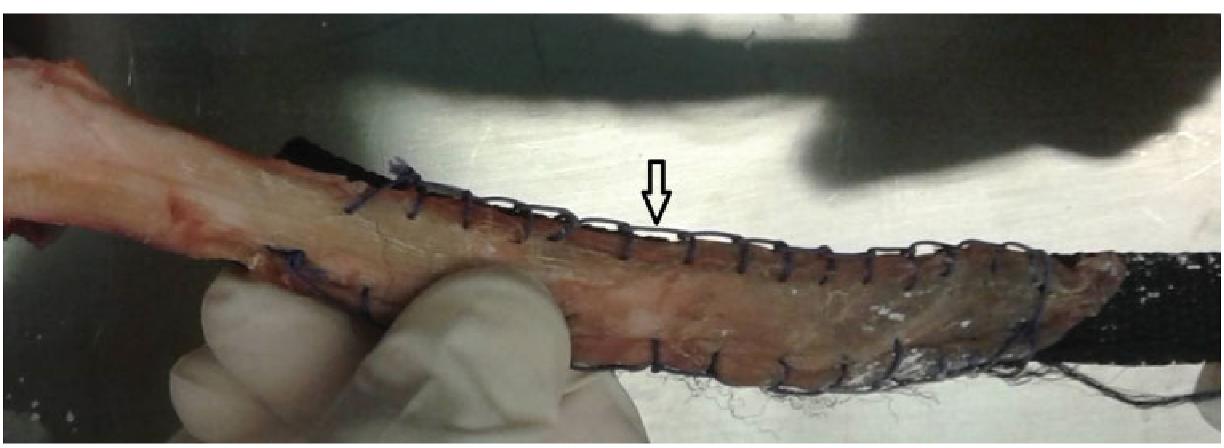

Fig. 1 Anatomical dissection of the infraspinatus tendon of a lamb. Standardized anatomical dissection removing all soft tissue associated with the humeral shaft, subscapular fossa, and supraspinatus fossa to isolate the infraspinatus muscle and its tendon. The tendon was fixated to a polypropylene nylon tape using a Krackow-type suture with MaxBraid #2 to enable muscle and tendon manipulation without tearing them.

Fig. 2 The model consisted of three fundamental parts: a modular support with adjustable height, an adjustable support for guidance of the suture system, and a linear actuator with an intermediate load cell. The humeral shaft was fixated with a metal clamp.

Fig. 3 Modular support. The modular support was adjusted to ensure that the tendon was parallel to a vertical line.

A prestressed repair was carried out with 10 N for 2 minutes. The load cell was then programmed for 1,000 cycles at a 2-Hz frequency and 30-N load. These parameters were consistent with those used in similar previous studies, and they reflect the initial period of postoperative rehabilitation (two weeks) with passive exercises with pendular movements.[32,33] No load-related failures were recorded regarding the repair, the tissue, or the support.

Statistical Analysis

The results were presented as mean ± standard deviation values. Since the distribution was normal, as revealed by the Shapiro-Wilk test, the statistical test for parametric variables (Student *t*-test) was used. All data were analyzed using the Stata (StataCorp., College Station, TX, US) software, version14. Statistical significance was set at $p < 0.05$.

Results

The pressure at the tendon-footprint interphase in response to cyclical loading (measured with a digital pressure sensor) in both repair models presented the self-reinforcement mechanism during increased cyclical stress (►**Figure 7**).

The average contact pressure curve at the tendon-footprint interphase after cycling and the average final residual contact pressure (time = 1,000 cycles) at the tendon-footprint

Fig. 4 Rotator cuff tear. A full-thickness, full-width tear is made with a #15 scalpel. The image shows the footprint of the infraspinatus tendon.

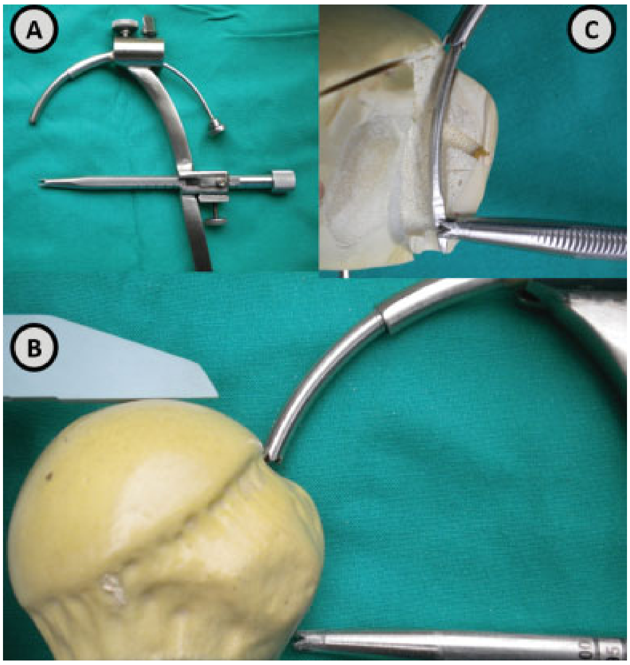

Fig. 5 Device for the design of oblique transosseous tunnels. Inset **A** shows the transosseous suture device used. Inset **B** shows the proper positioning of the instrument in relation to the greater tuberosity. Inset **C** shows a section of a Sawbone (Pacific Research Laboratories, Vashon, WA, US) model; note the oblique trajectory of the tunnel.

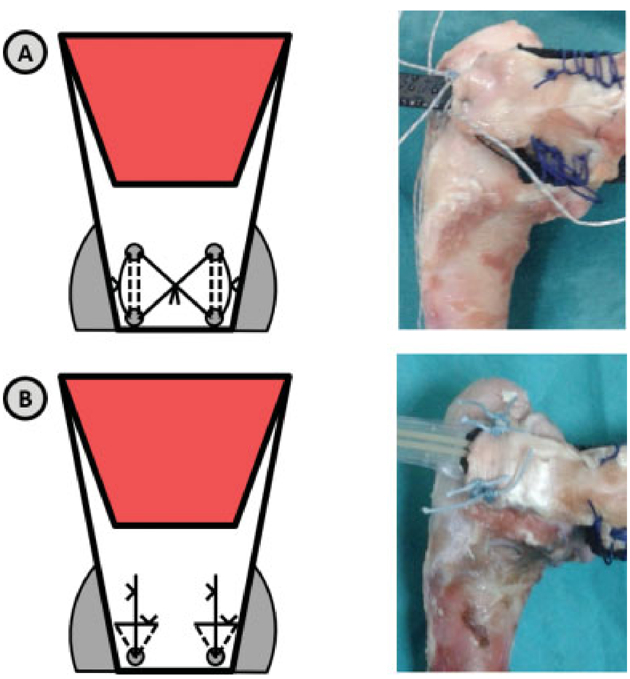

Fig. 6 Repair configurations. Inset **A** shows the transosseous repair with crossover suture, and inset **B** shows the repair with modified Mason-Allen suture.

interphase were compared. The average contact pressure curve was of 86.01 ± 8.43% in parts repaired with CTO sutures, and of 73.28 ± 12.01% in those repaired with MAM sutures ($p < 0.0004$). The average residual percentage at the end of cycling was of 71.57% for CTO sutures, and of 51.19% for MMA sutures ($p < 0.05$) (►**Figure 8**).

Discussion

The main finding of the present study was that CTO repair presents a higher average contact pressure curve and a higher percentage of final residual contact pressure at the tendon-footprint interphase when compared to the MMA suture after standardized cyclic loading. This may result in better healing rates regarding the footprint, leading to better clinical outcomes.

This is consistent with biomechanical studies[5,13] on DR repair showing an increased resistance to load-related failure, improved contact pressures and areas, and decreased gap formation at the tendon-footprint interphase compared to SR repair.

Caldow et al.[9] demonstrated the biomechanical inferiority of the TO technique (regarding contact area, contact pressure, tensile strength, and stiffness) compared to the MMA and DR repairs. Contact pressure for the TO repair was significantly lower compared to the MMA and DR repairs. The MMA repair demonstrated significantly higher maximum tensile strength compared to the TO repair; the DR repair had a significantly higher maximum tensile strength compared to the MMA and TO repairs. However, these findings are from a simple TO suture model, and the crossover repair was not evaluated. In a study not published by our group, the biomechanical properties of the crossover configuration were superior to those of the simple configuration in terms of contact area and pressure regarding the footprint.

Hinse et al.[34] compared the TO suture, TO tape and TO-equivalent technique, and demonstrated that the load at failure was not different in the TO tape and TO-equivalent technique. However, the TO suture had statistically significant lower resistance compared to the TO-equivalent technique, indicating that the material could be an important factor to consider. Furthermore, despite the lack of significant differences, this study revealed a trend to a greater loss of footprint coverage with pure TO techniques. Our study used MaxBraid #2, a high-strength suture recognized for its lower abrasive properties compared with other similar sutures,[35] but there are no studies comparing tapes in this type of model. We can infer that tapes from the same material would provide greater resistance to failure. Nevertheless, in this model, we did not register material failures under the loads of an initial rehabilitation.

Park et al.[12] compared simple TO, interrupted SR, and mattress SR sutures, demonstrating that the TO tunnel rotator cuff repair technique creates significantly greater contact and a greater overall pressure distribution on the defined footprint compared to the other techniques. However, they did not compare these techniques to the CTO or MMA configurations, which were evaluated in the present study. Tuoheti et al.[36] compared simple TO, SR and DR sutures, and found out that the DR was superior to the TO suture; however, this was a simple TO technique and DR with mattress suture, presenting weaknesses similar to those of the Park et al.[12] study.

However, these studies only evaluate biomechanical properties regarding pressure magnitude and distribution, as well as load to failure. The TO technique apparently has

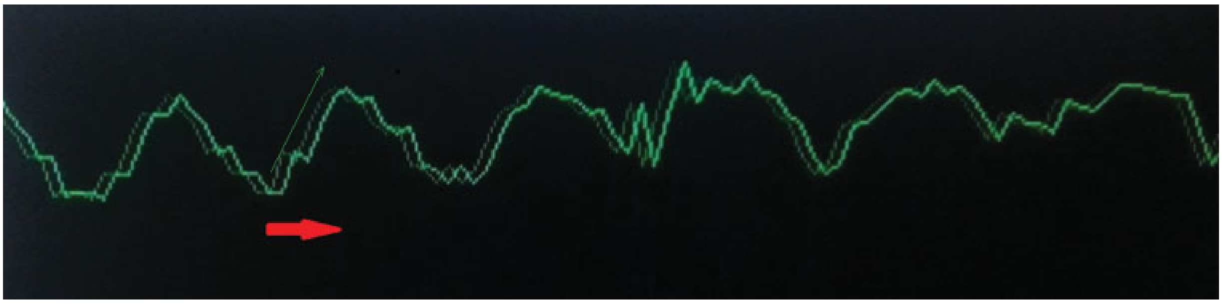

Fig. 7 Self-reinforcement mechanism in transosseous repair. Example of pressure measurement under cyclical loads, demonstrating the self-reinforcement phenomenon in transosseous repair. The red arrow represents the traction exerted on the tendon. The green arrow shows how the pressure increases at the footprint due to the applied load.

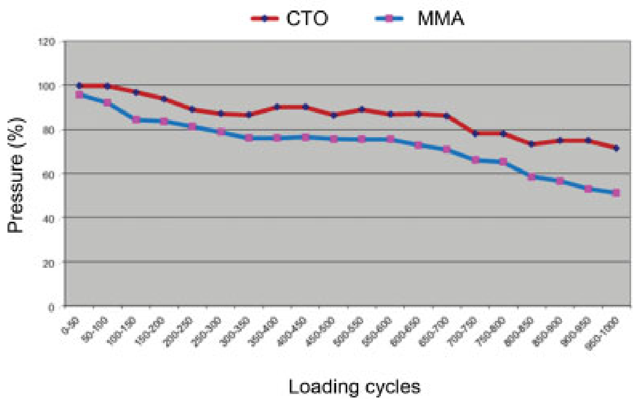

Fig. 8 Pressure percentage during cyclic loading. This figure shows how pressure (expressed as a percentage) decreases throughout the loading cycles for both repairs. Abbreviations: CTO, crossover transosseous suture; MMA, modified Mason-Allen suture.

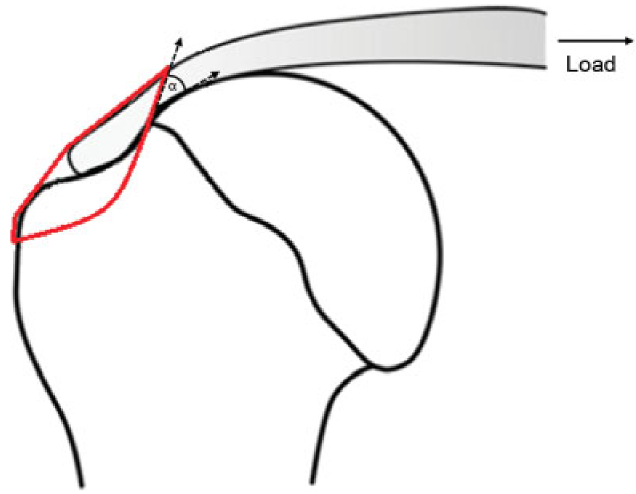

Fig. 9 Scheme of self-reinforcement in transosseous repair. Schematic illustration of the angle between the suture material and the bone as the tendon is progressively stressed, and suture geometry at the coronal plane changes from rectangular to trapezoidal as tensile load increases.

healing benefits due to the mesenchymal cell supply and better tendon vascularization.[24–26] Urita et al.[37] revealed that vascularization demonstrated by an ultrasound scan is superior in patients submitted to TO arthroscopic repair compared to equivalent TO techniques. This could reflect another benefit of the TO technique in improving healing.

Self-reinforcement is a mechanism described by Burkhart et al.[27] in 2009, in which an increased stress applied to the construct increases resistance to structural failure by progressively increasing compression forces at the tendon footprint. The compressive forces created at the footprint increase the resistance to friction between thehe tendon and tbone, thus reducing the formation of gaps between these two surfaces.[27] This phenomenon was observed in both repair techniques. The angle between the suture material and the bone is probably reduced as the tendon is progressively stressed; in addition, suture geometry at the coronal plane changes from rectangular to trapezoidal as the tensile load increases.[27] This results in an elastic deformation of the tendon, creating a compression force perpendicular to the bone surface, which increases as the tensile load increases (►**Figure 9**).[27]

Lastly, in addition to the biomechanical and biological advantages of the TO technique, it can present a better cost-effectiveness relationship due to device reuse and the low cost of high-resistance sutures compared to other construct types. However, these assertions were not evaluated here.

A limitation of the present study was the evaluation of biomechanical aspects alone in an animal model; as such, the findings may be different in humans and under biological conditions (consider mesenchymal cells and irrigation). Human cadaver shoulders would best represent the clinical population. On the other hand, the use of this model standardizes our results because each specimen is 6 months old; therefore, it is easily comparable to the others. This is also true for bone mineral density, which was not calculated for our specimens, but would have been very similar at the same age.

We conclude that the CTO repair presents superior biomechanical properties at the tendon-footprint interphase than the MMA repair after standardized cyclic loading. This finding may have important clinical repercussions on healing rates and functional outcomes, but the applicability of this device in the surgical environment and its potential use in an arthroscopic technique must be evaluated.

Conflict of Interests
The authors have no conflict of interests to declare.

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