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Suture anchor repair yields better biomechanical properties than transosseous sutures in ruptured quadriceps tendons

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Abstract
Purpose This human cadaveric study compares the biomechanical properties of quadriceps tendon repair with suture anchors and the commonly applied transosseous sutures. The hypothesis was that suture anchors provide at least equal results concerning gap formation and ultimate failure load compared with transosseous suture repair.
Methods Thirty human cadaveric knees underwent tenotomy followed by repair with either 5.5-mm-double-loaded suture anchors [titanium (TA) vs. resorbable hydroxyapatite (HA)] or transpatellar suture tunnels using No. 2 Ultrabraid$^{\text{TM}}$ and the Krackow whipstitch. Biomechanical analysis included pretensioning the constructs with 20 N for 30 s and then cyclic loading of 250 cycles between 20 and 100 N at 1 Hz in a servohydraulic testing machine with measurement of elongation. Ultimate failure load analysis and failure mode analysis were performed subsequently.
Results Tendon repairs with suture anchors yielded significantly less gap formation during cyclic loading (20th–250th cycle: TA 1.9 ± 0.1, HA 1.5 ± 0.5, TS 33.3 ± 1.9 mm, $p < 0.05$) and resisted significantly higher ultimate failure loads (TA 740 ± 204 N, HA 572 ± 67 N, TS 338 ± 60 N, $p < 0.05$) compared with transosseous sutures. Common failure mode was pull-out of the eyelet within the suture anchor in the HA group and rupture of the suture in the TA and TS group.
Conclusion Quadriceps tendon repair with suture anchors yields significantly better biomechanical results than the commonly applied transosseous sutures in this human cadaveric study. These biomechanical findings may change the future clinical treatment for quadriceps tendon ruptures. Randomised controlled clinical trials are desirable for the future.
Level of evidence Not applicable, controlled laboratory human cadaveric study.

Keywords Quadriceps tendon repair · Suture anchors · Transpatellar tunnels · Transosseous sutures · Biomechanics

Introduction

Incidences of ruptures of tendons and ligaments are reported as 166,6/100,000 per year for males and 52,1/100,000 per year for females [6]. Ruptures of the quadriceps tendon usually occur based on degenerative changes [21] caused by e.g. reduced blood supply, repetitive microtrauma, diabetes mellitus, renal failure [13, 15, 23], influence of steroids [25] and previous knee surgery [11]. Direct trauma by severe forces is rarer and mainly occurs in combination with complex injuries of the knee joint [11]. Bilateral quadriceps tendon ruptures are not uncommon [11, 13, 15, 25, 29]. Treatment can be conservative in case of preserved competence of the extensor mechanism [11]; otherwise, a surgical repair is mandatory.

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Successful repair of tendons is impeded by impact of high mechanical loads and poor blood supply [2]. Both the strength of the repair and the risk of wound complications grow with increased number of strands and calibre of the suture [1]. The established method of repair is sutures passing through transpatellar tunnels, with several operative modifications that have been introduced within the last years. Referring to the good biomechanical results of suture anchor repair in shoulder surgery and their advantages of less tissue dissection [3], the aim of this study was to evaluate the biomechanical properties of suture anchor repair in quadriceps tendon ruptures. The clinical aim was to provide scientific background for the choice of the best repair of quadriceps tendon ruptures in the future. Besides the established nonresorbable titanium anchors, bioresorbable suture anchors get more and more popular. Therefore, a comparison of titanium anchors, bioresorbable hydroxyapatite anchors and transosseous sutures was performed. The hypothesis was that suture anchors provide at least equal results concerning gap formation and ultimate failure load compared with transosseous suture repair.

Materials and methods

The knees of 15 human cadavers (30 knees) were used for acquisition of the quadriceps tendons and patella. The knee extensor structures were harvested in toto from the quadriceps femoris muscle to the tibial tuberosity to ensure the integrity of the quadriceps tendon and patella. The mean age of the cadavers from which the tissue was obtained was 52 ± 13 years in the hydroxyapatite anchor (HA) group, 68 ± 4 years in the titanium anchor (TA) group and 62 ± 8 years in the transosseous suture group. Cadavers of the titanium anchor group were significantly older compared with the hydroxyapatite anchor group ($p < 0.05$). There was no difference in age between the other groups.

The tendons were harvested at an average 1.3 ± 0.3 days post-mortem. We used tendons from 13 men and 2 women. There were no visual signs of tendon degeneration.

Tendons were cleaned from remaining muscle tissue by sharp dissection. After harvesting, the tendons were deep-frozen. The constructs were then thawed at 4 °C for 24 h prior to suturing and mechanical testing and kept moist using saline spray during the entire procedure.

According to the most common clinical rupture site, the simulation of tendon rupture was created by tenotomy with a scalpel blade approximately 3 mm from the edge of the superior pole of the patella [5]. The proximal quadriceps tendon end and the patella were then rigidly fixed in two clamps at their ends. All repairs were performed by the same experienced orthopaedic surgeon.

Sutures were performed in three different techniques. For the standard transosseous suture repair, three transpatellar tunnels were drilled vertically through the patella. An additional incision in line with the fibres of the patellar tendon allowed the passage of sutures. The quadriceps tendon was then repaired by four separate sutures [No. 2 Ultrabraid^{TM} (Smith and Nephew Orthopaedics, Tuttlingen, Germany)] with the Krackow whipstitch technique, tying knots at the end of the transpatellar tunnel [3, 17] (Fig. 1).

For the suture anchor repair, two 5.5-mm double-loaded suture anchors (titanium vs. resorbable hydroxyapatite) fitted with No. 2 Ultrabraid^{TM} sutures (Smith and Nephew Orthopaedics, Tuttlingen, Germany) were inserted a few millimetres out from the centre of the superior pole of the patella, dividing the patella into almost equal thirds [3]. The suture of the tendon itself was again performed in the same Krackow whipstitch technique [17] as in the tunnel group (Fig. 2).

The distribution of tendons into the three groups with ten constructs in each group was performed with regard to equal numbers of right and left knees, and comparable age, body mass index (BMI) and tendon diameter in each group. The biomechanical set-up was chosen according to an established method for testing of patellar tendon repairs recently reported [7].

For biomechanical evaluation of the constructs, each specimen was placed into a tensile loading fixation of a servohydraulic testing machine (Mini Bionix 858, MTS Systems Co., Minneapolis, USA) (Fig. 3). The sutured tendons were pretensioned with 20 N for 30 s prior to testing. Then, 250 cycles of mechanical loading between 20 and 100 N were applied at a repetition rate of 1 Hz. The increase in construct length was recorded with a frequency of 20 Hz and a measurement accuracy of 0.1 mm. Length changes are reported between the minimum of the first and the maximum 250th cycle. After a decreasing preload from 20 to 10 N and pausing for 30 s, a failure test with a ramp speed of 20 mm/s was performed. The maximum failure load and failure mode of the constructs were analysed.

All procedures were approved by the Ethics committee of Hannover Medical School, Germany.

Statistical analysis

All statistical analyses were performed using Statistical Package for Social Sciences (SPSS 15.0, SPSS Inc., Chicago, IL, USA). Normal distribution was analysed by the Shapiro–Wilk test. All values are presented in the form of mean ± standard deviation (SD). ANOVA test was used for parametric data and Kruskal–Wallis test for nonparametric data. A p value <0.05 (two tailed) was considered to be statistically significant.

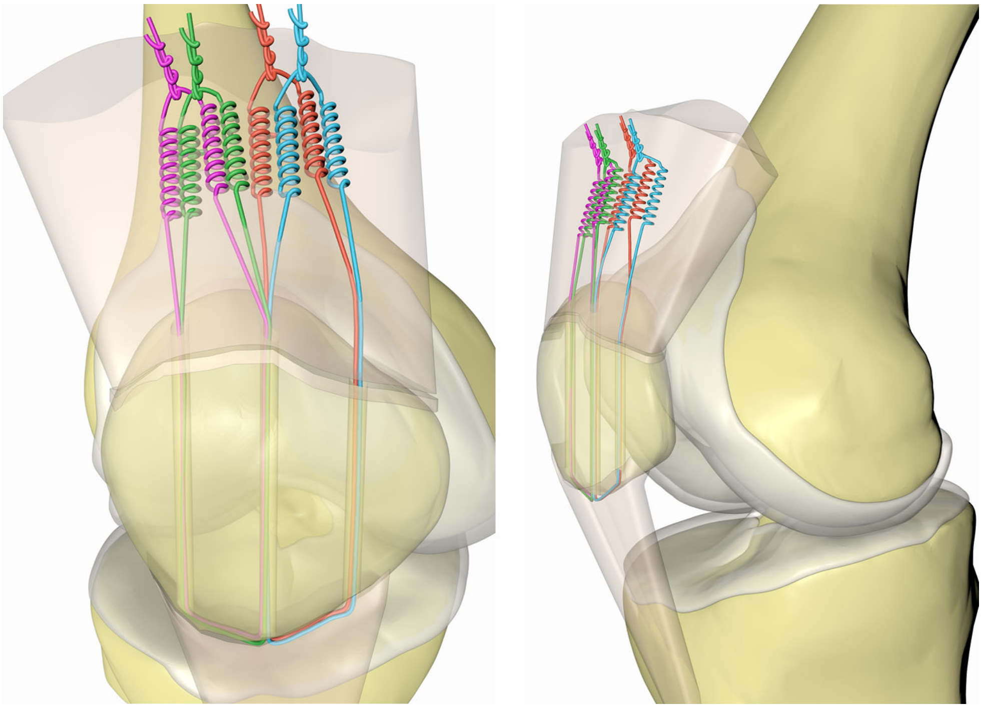

Fig. 1 Transosseous suture repair by four separate sutures with No. 2 Ultrabraid sutures with the Krackow whipstitch technique; knots were tied at the quadriceps tendon end

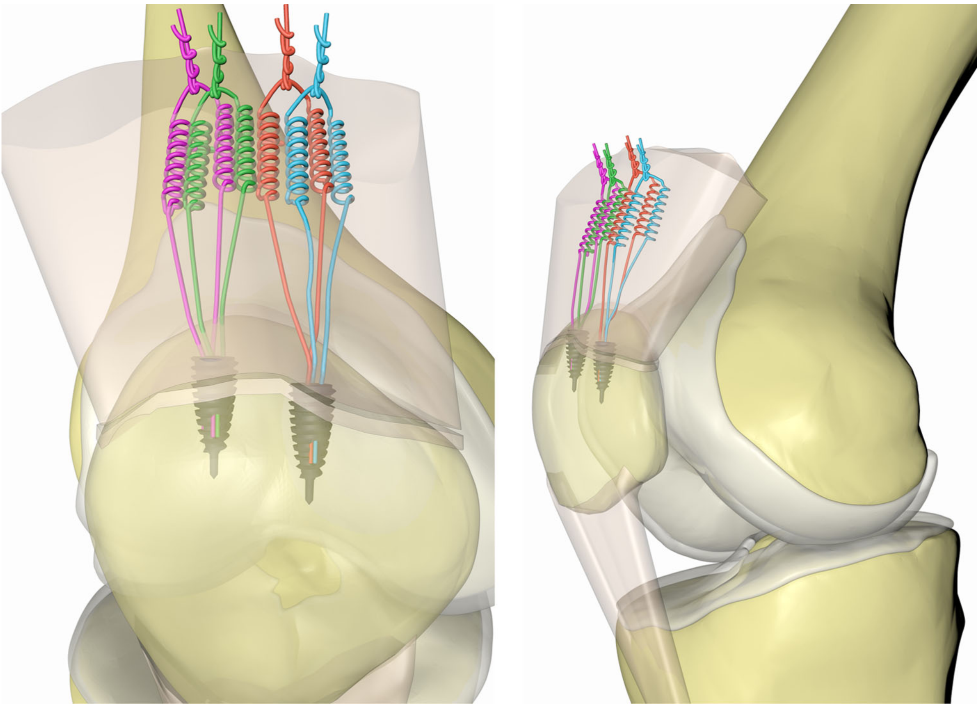

Fig. 2 Suture anchor repair by two 5.5 mm anchors fitted with two No. 2 Ultrabraid sutures each. The anchors consisted of either titanium or hydroxyapatite. Repair of the tendon was performed with the same Krackow whipstitch technique as in the tunnel group

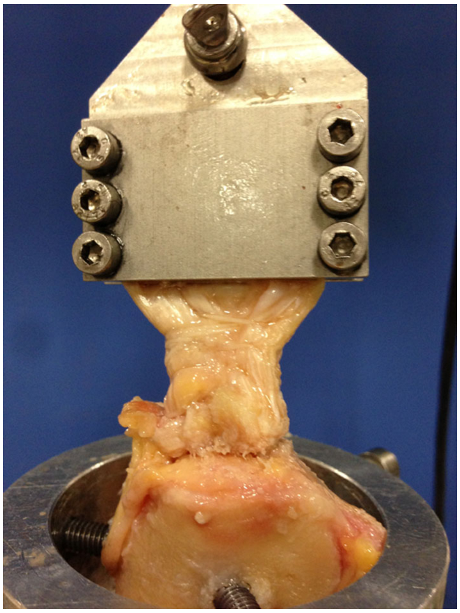

Fig. 3 Set-up for biomechanical evaluation of the constructs with the tensile loading fixation of a servohydraulic testing machine (Mini Bionix 858, MTS Systems Co., Minneapolis, USA)

Results

Cyclic loading

Compared with transosseous sutures, tendon repairs with suture anchors yielded significantly less gap formation during initial cyclic loading. Between the first and the 20th cycle, the titanium anchor group showed an elongation of 3.2 ± 0.5 mm, the hydroxyapatite anchor group showed 3.9 ± 0.8 mm, and the transosseous suture group showed an elongation of 12.2 ± 3.2 mm. Between the 20th and the 250th cycle, the titanium anchor group showed an elongation of 1.9 ± 0.1 mm, the hydroxyapatite anchor group showed an elongation of 1.5 ± 0.5 mm, and the transosseous suture group showed an elongation of 33.3 ± 1.9 mm. The elongation was significantly smaller for the suture anchors compared with the transosseous suture technique between the first and the 20th cycle and between the 20th and 250th loading cycle ($p < 0.05$; Fig. 4). There was no significant difference between the TA and HA group ($p > 0.05$).

Maximum failure load

The maximum load to failure was 740 ± 204 N in the titanium anchor group, 572 ± 67 N for the hydroxyapatite anchor group and 338 ± 60 N for the transosseous suture group. The suture anchors showed significantly higher failure loads compared with the suture technique ($p < 0.05$; Fig. 5).

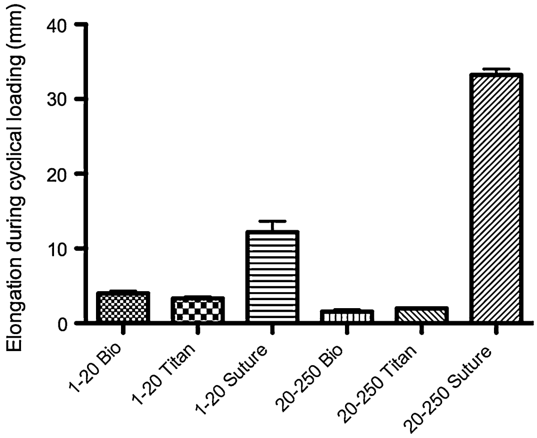

Fig. 4 The elongation was significantly smaller for the suture anchors compared to the suture technique between the first and the 20th cycle and between the 20th and 250th loading cycle ($p < 0.05$)

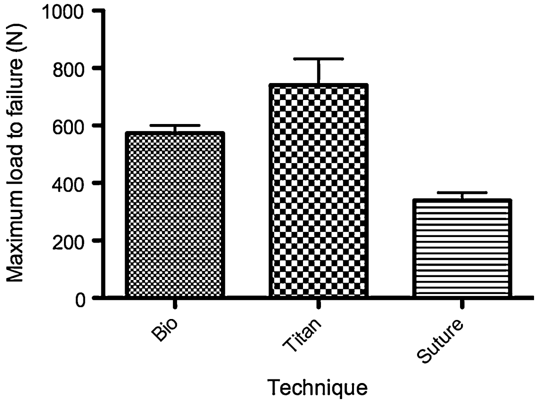

Fig. 5 The maximum load to failure was 740 ± 204 N in the titanium anchor group, 572 ± 67 N for the hydroxyapatite anchor group and 338 ± 60 N for the transosseous suture group. The suture anchors showed significantly higher failure loads compared to the suture technique ($p < 0.05$)

Failure mode

The failure mode in the titanium anchor group was a bone pull-out in 7/10 (Fig. 6) and a tendon pull-out in 3/10. The hydroxyapatite anchor group failed due to a suture failure at the anchor eyelet in 8/10 and a tendon pull-out in 2/10. The transosseous suture group failed in 2/10 due to a knot failure and in 8/10 due to a tendon pull-out.

Discussion

The most important finding of our study was that suture anchor repairs of quadriceps tendon ruptures showed less gap formation during cyclic loading and were able to sustain higher ultimate failure loads than transosseous suture repairs.

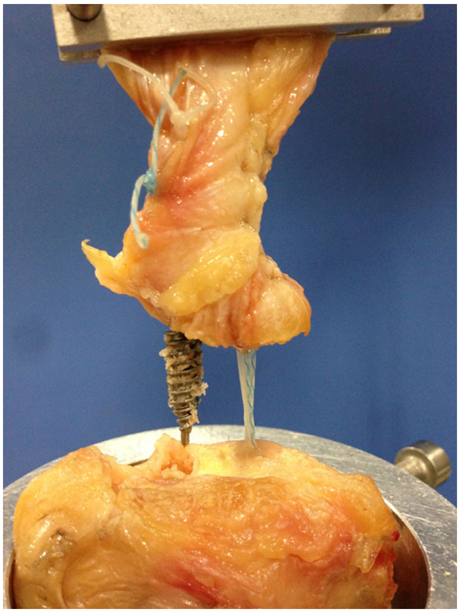

Fig. 6 Bony anchor pull-out failure of a titanium anchor during ultimate failure load testing

The standard procedure consists of refixing the tendon with sutures in transpatellar tunnels [5, 9, 15, 23], sometimes combined with additional augmentation [5, 9, 23]. Post-operative rehabilitation after quadriceps tendon repair used to be rather defensive for a long time, but a recent therapeutic study could show equal safety and complication rates for full weight bearing and early functional mobilisation post-operatively [19].

As common in biomechanical studies of ligament and tendon repairs, we investigated cyclic loading and ultimate failure load of the constructs. Cyclic loading represents more adequately the in vivo conditions during regular functional rehabilitation after tendon repairs [1]. On the other hand, ultimate failure testing represents the occurrence of a high load event, which may happen unintentionally and lead to suture failure [2].

In a bovine Achilles tendon rupture model, sutures in a four-strand Krackow technique with No. 2 polyblend sutures (Fiberwire^{TM}) provided 260 % higher ultimate failure load and 33 % less gap formation on cyclic loading compared with a No. 2 polyester suture (Ethibond^{TM}). Differing from our findings, all of these specimens failed at the knot with no suture pull-out from the tendon [1].

Analysis of various cutout parameters of different transosseous sutures in sawbones revealed that No. 5 polyester suture (Ethibond®; Ethicon, Somerville, NJ) and No. 5 polyblend suture (FiberWire®; Arthrex, Naples, FL) sustained higher cutout loads than the same sutures in No. 2. The cutout loads for Ethibond® were lower compared with FiberWire® [24].

As demonstrated in a comparable cadaveric study investigating patellar tendon ruptures by Krushinski et al. [18], pretensioning the patellar tendon sutured in the Krackow technique with cycling of the knee ten times from 90° to 5° of flexion revealed no relevant decrease in gap formation [18]. We therefore applied the pretensioning model established in a biomechanical study from 2012 investigating tendon suture materials and techniques [26]. Krushinskis findings correspond well to our results, showing rather high and early gap formation during cyclic loading of the transosseous sutures. This may be caused by the longer distance that has to be bridged by pure suture material compared with the suture anchor technique.

Even though there are now a large and continuously increasing number of studies dealing with suture anchors in shoulder surgery, data about suture anchor repair in knee surgery are sparse until today, with a few case reports and case series and only three biomechanical studies. The most recent biomechanical study investigating patellar tendon ruptures revealed significantly better properties for suture anchor repair compared to transosseous sutures [7].

Maniscalco et al. [22] published a case report describing their repair of a quadriceps tendon rupture at the tendon–bone junction with suture anchors. Their patient started active knee movement 3 weeks after surgery and started unassisted full weight bearing 6 weeks after the repair. The 2-year outcome of their patient was excellent, including return to sports activities and equal quadriceps strength bilaterally.

Richards et al. [27] reported two cases of quadriceps tendon ruptures, also at the tendon-bone junction, repaired by two suture anchors. Their patients performed isometric exercises and partial weight bearing for the first 2 weeks after surgery, followed by limited range of motion by brace protection for another 4 weeks. They reported encouraging clinical results as well. A successful delayed repair of the quadriceps tendon with suture anchors was reported in 2006 [14]. Bushnell et al. [4] reported five clinical cases of suture anchor repair with good results in 2007. Kim et al. [16] described successful repairs of quadriceps tendon ruptures after total knee arthroplasty in three patients in 2011.

Lighthart et al. [20] performed the first biomechanical study comparing biomechanical properties of transosseous sutures with sutures anchors in quadriceps tendon ruptures in 2008. They found a difference neither for elongation during cyclic loading nor for ultimate failure loading.

In another human cadaveric set-up in 2012, Hart et al. [10] compared matched pairs of transosseous sutures to 5.5 mm suture anchors (Bio-Corkscrew from Arthrex, Inc., Naples, FL, USA) and 3.5 mm Bio-PushLock anchors (Arthrex, Inc., Naples, FL, USA). All repairs were performed with No. 2 FiberWire suture (Arthrex, Inc., Naples, FL), which makes the study well comparable to our set-up. They found no significant difference in stiffness, but significantly less ultimate tensile load for the suture anchor repair (447 ± 86 N) compared with the transosseous group (591 ± 84 N, $p = 0.04$). All of their suture failures occurred at the anchor eyelet.

This differs a lot from our own findings. However, the anchor eyelet appears to be the weak spot, especially in bio-anchors such as the HA-anchors from Smith and Nephew used in our study or the Bio-Corkscrew anchors from Arthrex used by Lighthart. This leaves room for further improvement in stability of the material, especially as the anchor eyelet failure did not occur in our titanium anchor group.

Of interest, Salata et al. [28] recently reported superior biomechanical properties for suture anchor repair of the rotator cuff compared to transosseous techniques with no differences between tunnel or suture configuration.

Regarding the weakening of bone stock by insertion of suture anchors, Kamath et al. [12] recently reported at least equally good results for Bankart repair with two double-loaded suture anchors compared to three single-loaded suture anchors. Additionally, to the lower weakening of bone, the fact of using four sutures compared with three may have influenced the result. In our opinion, this also applies for extensor mechanism repairs of the knee. A failure by anchor or suture pull-out of the bone appears more likely in bonestock weakened by several drillholes and tunnels.

Generally speaking, the reported advantages of the suture anchor technique include reduced operation time, easily accessible implantation site, higher strength and more consistent ultimate failure loads compared to transosseous sutures [7, 22, 27]. These aspects enable the surgeon to allow earlier functional rehabilitation, leading to faster remodelling and strengthening of the collagen fibres in the repaired tendon [22, 27].

As also discussed in biomechanical studies about patellar tendon ruptures, further advantages of suture anchors are smaller need of tissue dissection and damage and a potentially reduced risk of patellar fractures and intraarticular damage compared with transpatellar tunnels [3, 20]. To emphasise this, Gregory et al. [8] recently reported three cases of stress fractures of the patella after transosseous repair of the extensor mechanism of the knee joint. As disadvantages of the suture anchors, the higher cost for the repair has to be mentioned [20] as well as the potentially increased risk of infection and the difficult management of revision surgery in case of failed primary repair with suture anchors.

Several limitations apply to this study. First, as a cadaveric study, the biomechanical properties of the cadaver tendons are not fully comparable to the in vivo properties of tendons of human beings, even though tendons were harvested as shortly as possible post-mortem. Second, this controlled laboratory study reflects the biomechanical properties of quadriceps tendons without any biological healing or remodelling responses. Third, our cadaveric tendon lesion is not fully comparable to clinical cases with often degenerated and shortened tissue and weakened quality of patellar bone. Fourth, the cadaveric biomechanical set-up is seductive for a high risk of excessive tension and creation of a too rigid construct that would increase the risk of joint stiffness after surgery. This also represents a relevant clinical problem, even though a rigid construct would allow a more aggressive rehabilitation protocol. However, the results of our study may also be of potential interest regarding repair of other tendons and ligaments. Randomised controlled clinical trials comparing suture anchors to transosseous suture techniques are desirable for the future.

Conclusion

Quadriceps tendon repair with suture anchors yields significantly better biomechanical results than the commonly applied transosseous sutures. These findings may be of relevance for the future clinical treatment for quadriceps tendon ruptures. Randomised controlled clinical trials comparing suture anchors to transosseous suture repair are desirable for the future.

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