PATELLAR TENDON RÜPTÜRLERİNDE TAMİR VE AUGMENTASYON TEKNİKLERİNİN BİYOMEKANİK KARŞILAŞTIRILMASI

BIOMECHANICAL COMPARISON OF REPAIR AND AUGMENTATION TECHNIQUES IN PATELLAR TENDON RUPTURES

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ABSTRACT

PURPOSE: The aim of this study is to biomechanically compare the augmentation techniques used in the surgical treatment of patellar tendon ruptures.

MATERIAL AND METHODS: The study was carried out with sixty fresh-frozen bovine knees. Patellar tendon repair was performed with transosseous repair with Krackow or modified - Kessler suturing or suture anchor repair techniques. Dall-Miles cable, cerclage wire or polyester suture material was used for augmentation. each specimen was evaluated biomechanically by cyclic loading and static pullout tests.

RESULTS: Significantly lower cyclic elongation values were recorded in the transosseous repair with Krackow suture group (p <0.05) in the comparison of primary repair groups. Lower cyclic elongation and higher maximal tensile strength values were measured in the augmentation with Dall-Miles cable or cerclage wire groups than the other groups. Augmentation groups had higher maximal tensile strength values and lower gap formation than non-augmented groups.

CONCLUSIONS: In the surgical treatment of patellar tendon ruptures, augmentation biomechanically strengthens the initial stability of primary repair. The transosseous repair augmented with the Dall-Miles cable or cerclage wire can be said to be the most biomechanically stabilizing technique.

KEYWORDS: *patellar tendon ruptures; transosseous repair; augmentation; biomechanics*

ÖZET

AMAÇ: Bu çalışmanın amacı patellar tendonun farklı tamir ve augmentasyon tekniklerinin biyomekanik olarak karşılaştırılmasıdır.

YÖNTEM: Biyomekanik test, 60 adet dana dizi ile gerçekleştirildi. Dizler tenotomi sonrası titanyum sütür ankor ve polyester sütür ile Krackow ve modifiye Kessler sütürasyon yapılarak transosseoz tünel tekniği ile tamir edildi. Augmentasyon için Ethibond, Dall-Miles kablo ve tel serklaj kullanıldı. Her bir örnek, siklik yüklenme ve statik çekme ile biyomekanik olarak değerlendirildi.

BULGULAR: Primer tamir gruplarının karşılaştırılmasında, Krackow sütür ile transosseoz tamir grubunda anlamlı olarak daha düşük siklik uzama değerleri kaydedildi (p <0.05). Dall-Miles kablosu veya serklaj teli ile augmentasyon yapılanlarda diğer gruplara göre daha düşük siklik uzama ve daha yüksek maksimal gerilme kuvveti değerleri ölçüldü. Augmentasyon grupları, augmentasyon yapılmayan gruplardan daha yüksek maksimal gerilme direnci ve daha düşük gap oluşumu sergilemiştir.

ÇIKARIMLAR: Patellar tendon yırtıklarının tedavisinde kullanılan augmentasyon teknikleri tespitin stabilitesini kuvvetlendirmektedir. Dall-Miles kablosu veya serklaj teli ile augmente edilen transosseoz onarımın biyomekanik olarak en stabil teknik olduğu söylenebilir.

ANAHTAR KELİMELER: *patellar tendon rüptürü; transosseoz onarım; augmentasyon; biyomekanik*

INTRODUCTION

Patellar tendon is one of the most important components of the extensor mechanism of the knee joint. The incidence of patellar tendon injuries is reported to be as 0.68 / 100.000 and is frequently seen in active and athletic population under 40 years of age [1, 2]. Factors such as previous patellar tendinitis, repetitive microtrauma, repeated steroid injections, degenerative changes from previous knee surgery, prior bone tendon bone harvest, rheumatoid arthritis, chronic renal failure, anabolic steroids and systemic lupus erythematosus have been accused in etiology [2-7]. Rupture often occurs with

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rapid, eccentric contraction of the quadriceps muscle against full body weight [4, 8].

Surgical approach is the gold standard of the treatment of patellar tendon ruptures [9-11]. The aim of the surgical treatment is to restore strength of the tendon to allow optimum loading after repair, restoration of the extensor mechanism and patellofemoral joint biomechanics [2, 11, 12]. The most common surgical techniques are transosseous suture repair and suture anchor repair [2, 6-8, 10, 13, 14].

Catastrophic failure is the most serious complication after patellar tendon repair [14, 15]. In order to prevent failure, the patellar tendon is usually immobilized in the extension for six weeks following standard surgical repair [4, 13, 16]. However, prolonged immobilization is associated with limited flexion, muscle weakness, development of patella baja, formation of adhesion, recurrent pain and reduced patellar mobility [5, 10, 14, 16-18]. Various augmentation techniques have been described due to potential problems of the standard repair techniques. Augmentation techniques have gained popularity because it allows early rehabilitation, low failure rates, successful functional outcomes, minimal muscle strength loss and satisfactory range of motion levels compared with the standard repair procedure.

Augmentation techniques for patellar tendon repair improves the strength of fixation and reduce gap formation [9, 14, 19]. Different surgical techniques have been described using various materials for strengthening. [6, 8, 16, 17]. Augmentation materials and repair techniques are directly related to biomechanical properties of the augmentation techniques. In our knowledge, there are no studies evaluating the biomechanical effects of different augmentation techniques in transosseous suture repair and suture anchor repair techniques.

The aim of this biomechanical study was to evaluate augmentation techniques used in the treatment of patellar tendon ruptures. Our hypothesis is that the transosseous suture repair technique augmented with Dall-miles cable are related with less gap formation and improve strength of repair.

MATERIAL AND METHODS

Data collection

All procedures were carried out after approval of the local ethics committee (protocol number 4856). Sixty skeletally mature (mean age 2 years) fresh-frozen bovine knees were obtained from local abattoir. Samples without any degenerative or traumatic macroscopic pathology in bone and soft tissue were stored at -20 ° C until the test day. Prior to use, samples were thawed in water at room temperature (24 ° C) in 12 hours.

Sixty specimens were randomly divided into 3 groups for transosseous repair (n = 20) with Krackow suture technique, transosseous repair with modified - Kessler suture technique (n = 20) and suture anchor repair technique (n = 20). Twenty specimens in each group were randomly assigned to augmentation with cerclage wire (n = 5), Dall-Miles cable (n = 5), polyester suture material (n = 5) and without augmentation (n = 5) subgroups.

Bone mineral density analysis

Bone density was measured using computerized tomography (Toshiba, Aquillon 64, Toshiba Medical Systems, Otowara, Japan) before biomechanical testing. Osirix (Osirix, Geneva, Switzerland) software was used to assess bone density. Subchondral bone density was measured with Hounsfield Unit (HU). The mean subchondral bone density of all the specimens was 599.9 ± 103.8 HU (Range: 373.8 - 909.4 HU). The bone density of all samples was within the reference range of bone density in the healthy human population (282 - 1411 HU) [20].

Surgical technique

In all specimens, skin, subcutaneous tissue, medial and lateral menisci, and intraarticular ligaments were carefully resected. A transverse osteotomy was performed at the level of 5 cm distally of the tuberositas tibia. Each patellar tendon was cut transversely at the level of 3 mm distal to inferior patellar pole. After the creating patellar tendon injury, tendon repair was performed by transosseous repair with Krackow [21] or modified-Kessler [17] suture techniques, or suture anchor repair techniques.

Transosseous repair

For the transosseous repair, three parallel transpatellar vertical tunnels for Krackow repair technique and two parallel tunnels for modified-Kessler suture technique were created using a 2.5-mm drill. No. 5.0 polyester sutures (EthiBond, Ethicon, Somerville, New Jersey) on the patellar tendon were passed through the tunnels using a passing pin. Then the sutures were tightly knotted in the proximal patella [7] **(Fig. 1a-b)**

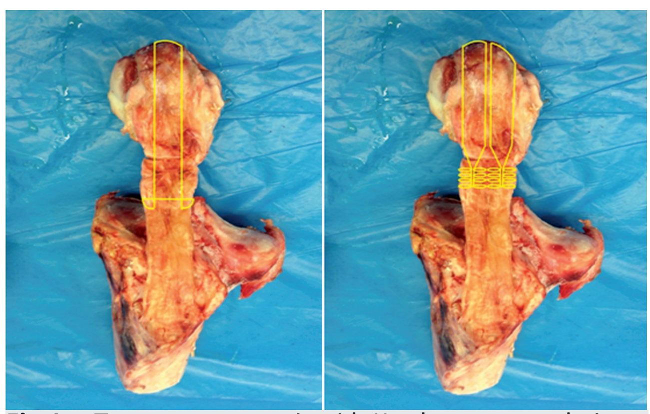


Fig.1a: Transosseous repair with Kessler suture technique.
Fig. 1b: Transosseous repair with Krackow suture technique

Suture anchor repair

3.5 mm titanium anchors with attached two No. 2 polyblend sutures (Fixlock®, Onarge, Ankara, Turkey) were used for suture anchor repair. Two titanium anchor were used for each specimen. Suture anchors were placed on the patellar tendon footprint on the patella distal pole. Repair was performed with Krackow suturing technique. After repair procedure, the sutures were knotted.

Augmentation:
No. 5.0 polyester sutures (EthiBond, Ethicon, Somerville, New Jersey), 2.0-mm Dall-Miles cable, or cerclage wire was used as augmentation material. Using a 3.5 mm drill, two transverse tunnels were formed from the mid-third of the proximal half of the patella and from the level of tuberosity tibia. The augmentation material was knotted laterally in the tibial tunnel after being passed through these tunnels. **(Fig. 2)**

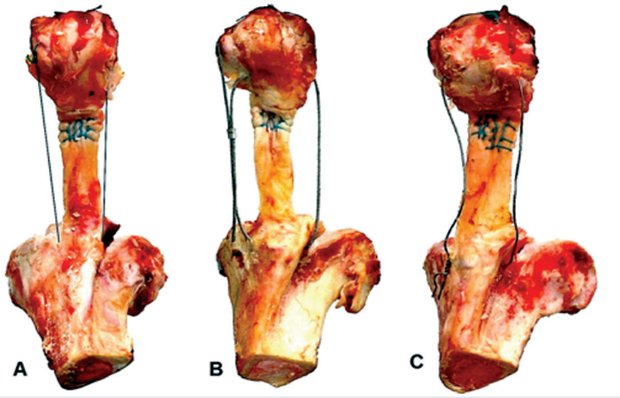


Fig. 2: Augmentation techniques; A: 5.0 polyester sutures, B: 2.0-mm Dall-Miles cable, C: cerclage wire.

Biomechanical test
A biomechanical testing protocol described by Ettinger et al. was used for cyclic loading. [7]. Cyclic loading was performed 2015EMY015 fatigue test machine (Labiotech, Ankara, TR). The specimens were placed on the testing device using high strength special rods.**(Fig. 3)**

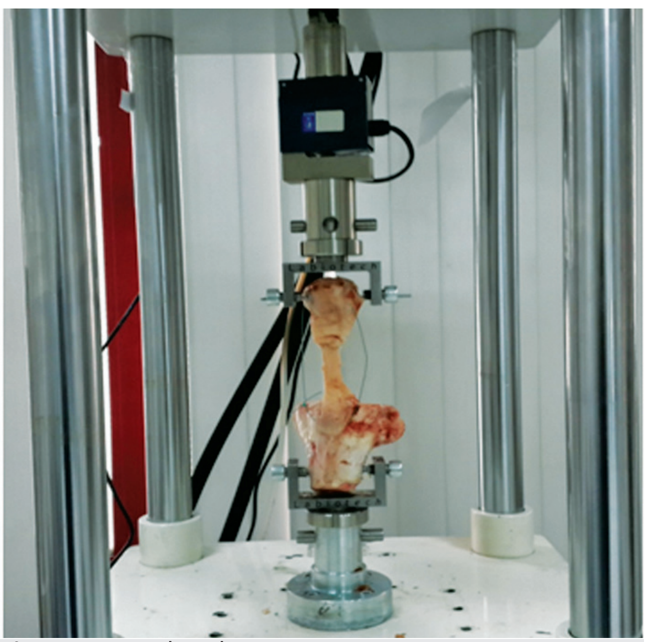


Fig. 3: Biomechinal testing system

Before cyclic loading, samples were pretensioned with 20 N for 30 seconds. Thereafter, 250 cycles of mechanical loading between 20 and 100 N were applied at a repetition rate of 1 Hz. Elongation- cycle curves were obtained during biomechanical test. Cyclic elongation values were recorded after 20 and 250 cycles. Following cyclic loading, a static pullout test was performed to determine the ultimate load. Static tension tests were performed at a strain rate of 20 mm/sec using a static tension device (Instron 3300®; Instron, Canton, MA, USA). During static tension test, load-displacement plots were obtained. The tests were stopped after a period of time as the load reached the peak and began to decrease. At the end of the static tensile test, the ultimate tensile strength (UTS) values were recorded at the tendon rupture point. Groups were compared with reference to the primary repair technique.

Statistical analysis
Statistical analysis was performed by using SPSS software (SPSS for mac, version 21, SPSS Inc, Chicago, IL, USA) The Kruskal-Wallis test was used for comparison between the groups. If a difference was detected, the Mann-Whitney rank-sum test was used to compare the groups as a post hoc analysis. The statistical significance level was accepted as $p < 0.05$.

RESULTS

Evaluation of primary repair technique
For biomechanical evaluation of primary repair techniques, data from without augmentation groups were used. Between the first and 20th cycle in the transosseous repair with Krackow suture group, significantly lower cyclic elongation values were measured than the modified-Kessler suture group ($p = 0.006$). Between the 20th and 250th cycle no significantly difference between groups ($p > 0.05$) **(Table 1)**

Table 1: Cyclic elongation and ultimate tensile strength values in the non-augmented groups. Values are expressed as mean ± standard deviation.*Represents the statistically significant difference between the groups.

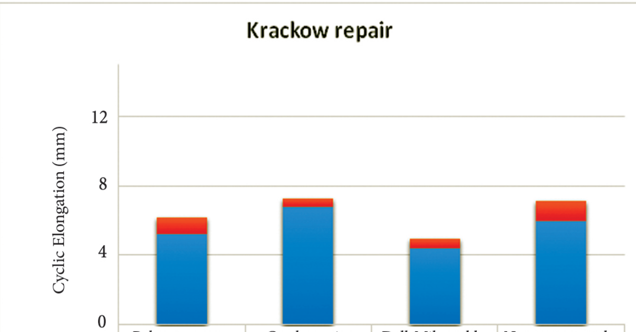
Repair Technique	Gap formation between the first and the 20th cycle (mm)	Gap formation between the 20th and 250th cycle (mm)	Ultimate tensile strength (N)
Krackow repair	6.00 ± 0.6*	1.12 ± 0.1	412.8 ± 125.4
Modified - Kessler repair	11.13± 1.0*	1.78 ± 0.5	282.0 ± 59.9
Suture anchor repair	9.87 ± 3.0	2.19 ± 1.0	329.0 ± 108.3
All groups	9.00 ± 2.8	1.70 ± 0.7	341.2 ± 109.5

The mean UTS value was measured as 341 ± 109 N. There was no significantly difference between groups in terms of UTS values (p = 0.1)

Evaluation of augmentation techniques according to repair techniques

Transosseous repair with Krackow suturing

Between the first and 20th cycle, in the augmentation with Dall-Miles cable group, significantly lower cyclic elongation values were measured than the cerclage wire group (p =0.02). Between the 20th and 250th cycle, lower cyclic elongation values were recorded in the augmentation with Dall-Miles cable group (0,504 ± 0,183 mm) and augmentation with cerclage wire (0,539 ± 0,185 mm) group than in non-augmented group (1,126 ± 0,094 mm) (p <0.05) **(Table 2).**



	Polyester suture	Cerclage wire	Dall-Miles cable	Non-augmented
Cycle20 - 250	0,95	0,53	0,50	1,12
Cycle1 - 20	5,20	6,76	4,43	6,00

Table 2: Cyclic elongation values in the Krackow repair groups

In the augmented with cerclage wire group, the mean UTS value was higher than the augmented with polyester suture and non-augmented groups (p <0.05).

Transosseous repair with modified-Kessler suturing

Between the first and 20th cycle, lower cyclic elongation values were recorded in the augmentation with Dall-Miles cable group (3,706 ± 1,525 mm) and augmented with polyester suture (5,525 ± 0,851 mm) group than in non-augmented group (11,132 ± 1,068 mm) (p <0.05). Between the 20th and 250th cycle the mean cyclic elongation value was significantly lower (p <0.05) in the augmentation with Dall-Miles cable group (0,755 ± 0,471 mm.) and augmentation with cerclage wire (0,531 ± 0,195 mm.) than in the non-augmented group (1,789 ± 0,519 mm.) **(Table 3).**

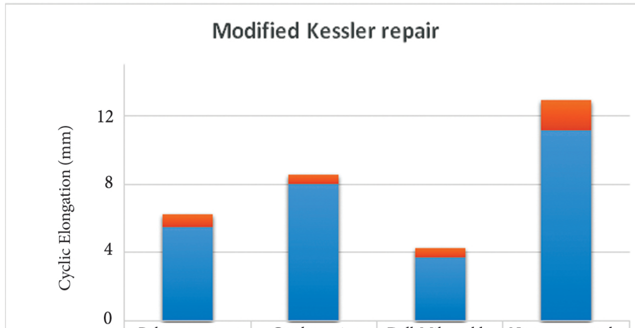
Similarly, greater mean UTS values were measured in augmentation with Dall-Miles cable and cerclage wire groups than non-augmented group (p <0.05).

Suture anchor repair

Between the first and 20th cycle there was no significantly difference between groups in terms of cyclic elongation values (p>0.05). Between the 20th and 250th cycle the mean cyclic elongation values were significantly lower in the augmentation with cerclage wire (0,605 ± 0,743 mm) group than in the non-augmented group (2,194 ± 1,027 mm) (p =0.01) **(Table 4).**

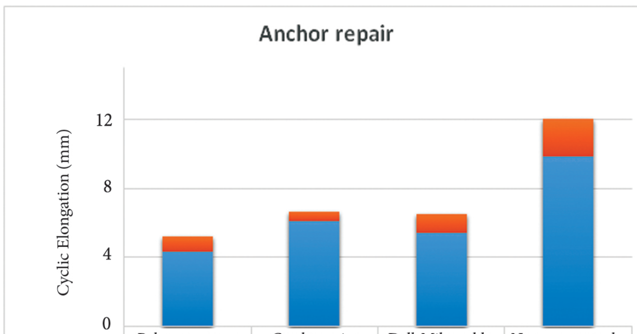
The mean UTS value in the augmentation with cerclage wire group was significantly higher than the augmentation with polyester suture and non-augmented groups (p <0.05).

Comparion of UTS values of all groups were summarized in table. 5 **(Table.5)**



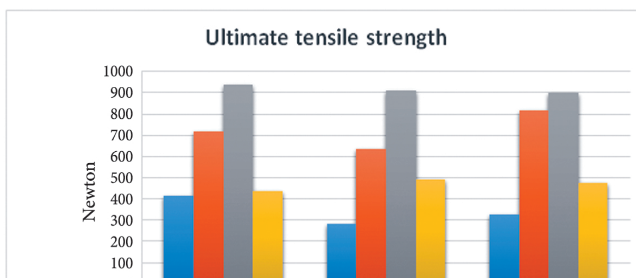
	Polyester suture	Cerclage wire	Dall-Miles cable	Non-augmented
Cycle20 - 250	0,75	0,53	0,54	1,78
Cycle1 - 20	5,52	8,05	3,70	11,13

Table 3: Cyclic elongation values in the modified Kessler repair groups



	Polyester suture	Cerclage wire	Dall-Miles cable	Non-augmented
Cycle20 - 250	0,90	0,61	1,10	2,19
Cycle1 - 20	4,35	6,08	5,45	9,87

Table 4: Cyclic elongation values in the anchor repair groups



	Krackow	Modified-Kessler	Suture anchor
Non-augmented	412,8	282	329
Dall-Miles cable	717,2	636,2	815,8
Cerclage wire	935,4	910,4	898,2
Polyester suture	434,4	494,2	477

Table 5: Ultimate tensile strength values in the all groups

DISCUSSION

The main finding of the current study is that the patellar tendon repair with Dall-miles cable augmentation have less gap formation during cyclic loading compared to other augmentation techniques. On the other hands this study also demonstrates that significantly higher UTS values were obtained in the augmentation with cerclage wire technique than in other repair techniques. In this context, it can be said that patellar tendon repair with augmentation is biomechanically superior to non-augmented repair techniques.

The main goals of surgical treatment of patellar tendon ruptures are; to maintain the continuity of the extensor mechanism, to regain patellofemoral joint function, to provide early mobilization of the patient and earn normal activities as soon as possible [14]. Many different surgical repair techniques have been described in the literature, including primary repair or repair with augmentation, but there is no consensus about the ideal surgical treatment approach [22]. Although relatively successful results have been reported due to primary repair without augmentation of the patellar tendon rupture, this technique has some potential problems such as joint stiffness due to prolonged immobilization, development of patella baja and delayed return of pre-injury activity level [5, 23].

Augmentation techniques have been described for strengthening tendon repair, avoiding prolonged immobilization, encouraging early weight bearing and knee joint motion. [17]. The purpose of augmentation application is that it acts as a temporary connection for the extensor mechanism in the active contractions of quadriceps, thus resisting the loading on the repair line [13]. There is limited number of studies in the literature evaluating the biomechanical effects of augmentation techniques in patellar tendon repair. In these studies, fixation by using additional augmentation techniques were reported to show a decrease gap formation compared to classical repair techniques [9, 13, 14, 19].

Many techniques have been described for augmentation in patellar tendon repair. Moreower, several materials such as non-absorbable sutures, polydioxanone suture (PDS), hamstring tendon aoutografts, cerclage wires, Dall-Miles cable, polyester prosthetic ligaments, Dacron vascular grafts and Mersilene tape are used for augmentation[6, 8, 9, 13, 14, 16, 17, 19, 24]. Therefore, although there is limited study in the literature, there is lack of standardization in the repair techniques and the preferred augmentation materials for biomechanical comparisons. For this reason, in the current study, biomechanical behaviors of repair and augmentation techniques were tried to be explained by applying standard protocols.

Black et al. compared biomechanical performance of traditional trasosseos suture repair technique by using polyester suture material versus augmentation with figure-of-eight suture technique with transosseous suture technique [14]. They have seen, 68% less gap formation at 250 cylcle in augmentation group. In the same study, 13% greater mean load to failure values were obtained in the augmentation compared with the transosseous repair. Mihalko et al. compared the standard transosseous tendon repair technique with augmented repair using the hamstring tendon [19]. They reported the mean gap formation at the end of 250 cycles as 7.2 mm in the standard transosseous repair and 13.2 mm in the augmented group. Schliemann et al. biomechanically compared of patellar tendon repair techniques with a cable wire or polydioxanone suture cord augmentation with a suture-anchor repair technique [9]. They achieved significantly higher maximum loads under load to failure testing and less cyclic elongation after augmentation with a cable wire or a polydioxanone suture.

In their biomechanical studies, Ravalin et al. compared the primer transosseous patellor repair technique via Krackow suturing technique without augmentation with a No. 5 polyester suture or a Dall-Miles cable augmentation technique. [13]. At the end of 250 cycles; cyclic elongation values were calculated as 3.5 mm in the Dall-Miles augmentation group, 4.9 mm in the polyester suture augmentation group and 7.3 mm in the without augmentation group. The results of the current study are similar to those of Ravelin et al.'s work, but also demonstrate the biomechanical superiority of augmentation technique with cable wire.

The most common surgical repair techniques used in the treatment of patellar tendon ruptures are transosseous repair and repair with suture anchors [7, 12, 25]. In studies comparing both techniques, biomechanically superior results were reported with the anchor repair technique compared with the transosseous repair technique.

In biomechanical testing, there are many parameters that affect fixation, such as the applied surgical technique, the material used, and the stitching technique. Suture material and its thickness are the most important parameters determining the durability of fixation in tendon repair. Polyblend suture materials are biomechanically superior to polyester suture materials and tend to have less gap formation in tendon repair with these materials [26, 27]. In cyclic loading tests, less gap formation was obtained in thick suture materials compared to thin materials. [27]. The lack of standardization of the biomechanical properties of materials used in previous biomechanical studies may lead to different results between studies. On the other hand, the suturing technique directly affects the biomechanical properties of the repair. This study demonstrates that patellar tendon repair using Krackow suturing technique is biomechanically superior to modified Kessler suturing technique.

In a cadaver study, Ettinger et al. biomechanically compared transosseous repair using Krackow suturing technique performed via No. 2 Ultrabraid sutures and anchor repair in patellar tendon rupture model. [7] In the anchor repair group, less gap formation and higher ultimate failure loading values were obtained compared to the transosseosis repair group. Bushnell et al. compared transosseous repair using suture anchors with two suture type (No. 5 Ethibond and No. 2 FiberWire) and suture anchors with No. 2 FiberWire in patellar tendon rupture cadaver model [8]. They achieved less gap formation in the anchor group at 250 cycles. In the same study, there was no difference between the groups as load to failure. Conversely, in the current study, there was less gap formation in the transosseous repair with the krackow technique group than the anchor repair group. This difference may be due to the use of polyester No. 5 suture for transosseous repair in the current study. Therefore, the high gap formation obtained in anchor repair may be related to the using of No.2 polyblend sutures.

This study has some limitations. The main limitation of this study is that it is carried out using bovine knees. Bovine specimens, which are relatively inexpensive and easy to obtain materials, are commonly used in biomechanical studies. [2]. Another limitation of this study is that the sample size is relatively small. However, the study design allows standard test protocols to be applied to many scenarios. In addition, it can be said that experiments performed in vitro conditions may not reflect the in vivo biomechanics of the knee joint. However, in the current study, in addition to the static pullout test, cyclic loadings were applied to simulate regular functional rehabilitation after tendon repair [7]. However, in situations that affect the intrinsic structure of the tendon, such as tendinopathy, biomechanical experiments are less likely to simulate physiological behaviors [22]. In this biomechanical study, different scenarios were simulated by combining different repair and augmentation techniques. In our knowledge, there are no studies in the literature evaluating a large number of techniques for the repair of patellar tendon ruptures with the standard biomechanical testing protocol.

CONCLUSIONS

As a result; augmentation in patellar tendon repair increases the biomechanical stability of primary repair. Transosseos primer repair without augmentation is a biomechanically more stable fixation compared with nonaugmented anchor repair. It can be said that augmentation using Dall-miles cable or cerclage wire is generally the most stable repair method.

REFERENCES

1.)Clayton RA, Court-Brown CM (2008) The epidemiology of musculoskeletal tendinous and ligamentous injuries. Injury 39:1338-1344. doi:10.1016/j.injury.2008.06.021

2.)Lanzi JT, Jr., Felix J, Tucker CJ, Cameron KL, Rogers J, Owens BD, Svoboda SJ (2016) Comparison of the Suture Anchor and Transosseous Techniques for Patellar Tendon Repair: A Biomechanical Study. Am J Sports Med 44:2076-2080. doi:10.1177/0363546516643811

3.)Sanchez G, Ferrari MB, Sanchez A, Moatshe G, Chahla J, DePhillipo N, Provencher MT (2017) Proximal Patellar Tendon Repair: Internal Brace Technique With Unicortical Buttons and Suture Tape. Arthrosc Tech 6:e491-e497. doi:10.1016/j.eats.2016.11.004

4.)Roudet A, Boudissa M, Chaussard C, Rubens-Duval B, Saragaglia D (2015) Acute traumatic patellar tendon rupture: Early and late results of surgical treatment of 38 cases. Orthop Traumatol Surg Res 101:307-311. doi:10.1016/j.otsr.2014.12.017

5.)Marder RA, Timmerman LA (1999) Primary repair of patellar tendon rupture without augmentation. Am J Sports Med 27:304-307. doi:10.1177/03635465990270030601

6.)Otsubo H, Kamiya T, Suzuki T, Kuroda M, Ikeda Y, Matsumura T, Yamashita T (2017) Repair of Acute Patellar Tendon Rupture Augmented with Strong Sutures. J Knee Surg 30:336-340. doi:10.1055/s-0036-1586725

7.)Ettinger M, Dratzidis A, Hurschler C, Brand S, Calliess T, Krettek C, Jagodzinski M, Petri M (2013) Biomechanical properties of suture anchor repair compared with transosseous sutures in patellar tendon ruptures: a cadaveric study. Am J Sports Med 41:2540-2544. doi:10.1177/0363546513500633

8.)Bushnell BD, Byram IR, Weinhold PS, Creighton RA (2006) The use of suture anchors in repair of the ruptured patellar tendon: a biomechanical study. Am J Sports Med 34:1492-1499. doi:10.1177/0363546506287489

9.)Schliemann B, Gruneweller N, Yao D, Kosters C, Lenschow S, Rosslenbroich SB, Raschke MJ, Weimann A (2016) Biomechanical evaluation of different surgical techniques for treating patellar tendon ruptures. Int Orthop 40:1717-1723. doi:10.1007/s00264-015-3003-4

10.)Gilmore JH, Clayton-Smith ZJ, Aguilar M, Pneumaticos SG, Giannoudis PV (2015) Reconstruction techniques and clinical results of patellar tendon ruptures: Evidence today. Knee 22:148-155. doi:10.1016/j.knee.2014.10.007

11.)Chen B, Li R, Zhang S (2012) Reconstruction and restoration of neglected ruptured patellar tendon using semitendinosus and gracilis tendons with preserved distal insertions: two case reports. Knee 19:508-512. doi:10.1016/j.knee.2011.07.007

12.)Gaines RJ, Grabill SE, DeMaio M, Carr D (2009) Patellar tendon repair with suture anchors using a combined suture technique of a Krackow-Bunnell weave. J Orthop Trauma 23:68-71. doi:10.1097/BOT.0b013e318191c353

13.)Ravalin RV, Mazzocca AD, Grady-Benson JC, Nissen CW, Adams DJ (2002) Biomechanical comparison of patellar tendon repairs in a cadaver model: an evaluation of gap formation at the repair site with cyclic loading. Am J Sports Med 30:469-473. doi:10.1177/03635465020300040301

14.)Black JC, Ricci WM, Gardner MJ, McAndrew CM, Agarwalla A, Wojahn RD, Abar O, Tang SY (2016) Novel Augmentation Technique for Patellar Tendon Repair Improves Strength and Decreases Gap Formation: A Cadaveric Study. Clin Orthop Relat Res 474:2611-2618. doi:10.1007/s11999-016-5009-7

15.)Bushnell BD, Tennant JN, Rubright JH, Creighton RA (2008) Repair of patellar tendon rupture using suture anchors. J Knee Surg 21:122-129

16.)West JL, Keene JS, Kaplan LD (2008) Early motion after quadriceps and patellar tendon repairs: outcomes with single-suture augmentation. Am J Sports Med 36:316-323. doi:10.1177/0363546507308192

17.)Massoud EI (2010) Repair of fresh patellar tendon rupture: tension regulation at the suture line. Int Orthop 34:1153-1158. doi:10.1007/s00264-009-0879-x

18.)Flanigan DC, Bloomfield M, Koh J (2011) A biomechanical comparison of patellar tendon repair materials in a bovine model. Orthopedics 34:e344-348. doi:10.3928/01477447-20110627-13

19.)Mihalko WM, Vance M, Fineberg MJ (2010) Patellar tendon repair with hamstring autograft: a cadaveric analysis. Clin Biomech (Bristol, Avon) 25:348-351. doi:10.1016/j.clinbiomech.2010.01.003

20.)Hoechel S, Schulz G, Muller-Gerbl M (2015) Insight into the 3D-trabecular architecture of the human patella. Ann Anat 200:98-104. doi:10.1016/j.aanat.2015.02.007

21.)Krackow KA, Thomas SC, Jones LC (1986) A new stitch for ligament-tendon fixation. Brief note. J Bone Joint Surg Am 68:764-766
22.)Maffulli N (2016) CORR Insights((R)): Novel Augmentation Technique for Patellar Tendon Repair Improves Strength and Decreases Gap Formation: A Cadaveric Study. Clin Orthop Relat Res 474:2619-2621. doi:10.1007/s11999-016-5065-z
23.)Kuechle DK, Stuart MJ (1994) Isolated rupture of the patellar tendon in athletes. Am J Sports Med 22:692-695. doi:10.1177/036354659402200519
24.)Lionberger DR, Correia N (2011) Protection of repaired patellar tendons a surgical technique. J Arthroplasty 26:969-971. doi:10.1016/j.arth.2011.04.005
25.)Capiola D, Re L (2007) Repair of patellar tendon rupture with suture anchors. Arthroscopy 23:906 e901-904. doi:10.1016/j.arthro.2006.10.023
26.)Benthien RA, Aronow MS, Doran-Diaz V, Sullivan RJ, Naujoks R, Adams DJ (2006) Cyclic loading of Achilles tendon repairs: a comparison of polyester and polyblend suture. Foot Ankle Int 27:512-518. doi:10.1177/107110070602700706
27.)Norris JB, Smith RT, White KL, Parks BG, O'Donnell JB (2010) Effect of suture size and type on bone cutout in transosseous tendon repairs. Arthroscopy 26:324-327. doi:10.1016/j.arthro.2009.08.020