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Research Article

Knotless anchors offer better prevention of meniscal excursion than knotted anchors: An experimental study of the bovine knee

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ABSTRACT

Objective: Due to the biomechanical importance of the meniscal root ligament, several surgical techniques have been defined in order to treat meniscal root tear. Different application techniques have different levels of difficulty. We aimed to find a stronger and simpler repair technique.

Methods: Sixteen bovine knee joints were prepared. The posterior root of the medial meniscus was dissected and repaired with one of two different techniques. The knees in group 1 ("knotted group") were repaired with the knotted suture anchor technique, and the knees in group 2 ("knotless group") were repaired using the knotless suture anchor technique. The strength of the repairs was tested biomechanically.

Results: Cyclic loading tests were done. On the 0–20 N one-cycle test, the knotted anchor group's equivalent stiffness average was 5.28 N/mm, and the knotless anchor group's equivalent stiffness average was 5.48 N/mm. The 5–20 N two-cycle test results were 8.29 N/mm for the knotted group and 8.66 N/mm for the knotless group. On the 5–20 N 100-cycle test, the equivalent stiffness averages were 8.59 N/mm for the knotted group and 10.18 N/mm for the knotless group. Elongation was 5.83 mm for the knotted group and 4.86 mm for the knotless group. After performing load-to-failure tests, the failure forces were recorded as 237.83 N for the knotted group and 204.90 N for the knotless group. The failure test elongation values were 26.83 mm for the knotted group and 18.70 mm for the knotless group. The failure energies were 3.87 J for the knotted group and 1.83 J for the knotless group. Except for elongation until failure ($p=0.009$), there were no significant differences between the two groups tested ($p>0.05$). The average elongation was significantly less in group 2, showing that the knotless anchor had an advantage, with less meniscal excursion compared to the sutured anchor.

Conclusion: Knotless anchors have a mechanical advantage over knotted anchors for preventing meniscal excursion. When thought together with technical simplicity during arthroscopic surgery, knotless anchors could be used safely for the fixation of the meniscal root ligament.

The meniscus has vital biomechanical functions such as load transmission through the joint without peak stresses at the bone, shock absorbance, and friction reduction at the joint. It increases the joint contact surface area, distributes contact forces to the articulating surfaces, and serves critical long-term functions such as the prevention of chondral damage (1, 2). Menisci can absorb 40% to 70% of the total body weight (3).

The meniscus has three segments: an anterior horn, a body, and a posterior horn. Four meniscal roots attach the medial and lateral menisci to the anterior and posterior tibial intercondylar region (4). The posterior root of the medial meniscus (PRMM) inserts the anterior and medial to the posterior cruciate ligament (PCL) on the posterior medial intercondylar eminence of the tibia. These four meniscal roots provide meniscal stability, which is vital to meniscus health. Meniscal root tears have dramatic effects on the knee joint, such as kinematical derangements and increases in tibiofemoral contact forces (5, 6). Previous studies have suggested that the posterior root of the medial meniscus maintains meniscal hoop tension and prevents meniscal excursion (7, 8).

Meniscal root tears (MRTs) are radial tears at the insertion of the meniscus. Even though the meniscal avulsion injury was first described in 1935 with

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a plain radiograph, soft tissue injury of the meniscal root was not defined until the invention of magnetic resonance imaging (MRI). The first soft tissue meniscal root tear was defined as a meniscal extrusion and treated conservatively. Advances in arthroscopy and MRI technology have contributed to the detection of meniscal root tears.

On the other hand, the relationship between meniscal extrusion and MRT is unclear. Extrusion can be a cause of early degenerative changes in the knee, while it can also originate from early degenerative changes. Some studies suggested that nonanatomic repairs used to prevent meniscal extrusion significantly impair the ability of the meniscus to convert axial forces into hoop stress (7). Therefore, the balance between preventing extrusion and preserving load transmission is critical for repairing MRTs. Meniscal root tears alter tibiofemoral joint contact forces (5, 7, 9). Several studies highlighted the changes in the contact area and peak contact pressure due to meniscal root tears (5, 6, 10, 11). Although repairing MRTs has a positive effect on the load transmission and contact area, the improvement it provides to the biomechanical functionality is controversial. Some studies reported the return of normal biomechanical capability after the repair (5, 6), while others noted limited improvements with no return to native biomechanical strength (10, 11).

An untreated MRT leads to early osteoarthritis (1, 8); therefore, many surgical repair strategies for the meniscal root tears have been developed. Two surgical techniques the pull-out suture and the all-inside anchor techniques are defined for root fixation. Numerous suture-based fixators (knotless and classical suture anchors) are currently employed. In comparison to a classical suture anchor, the knotless anchor allows single insertional fixation and obviates the need for suture management (12, 13).

MAIN POINTS

- Meniscal root tears (MRTs) are radial tears at the insertion of the meniscus. An untreated MRT leads to early osteoarthritis. Two surgical techniques the pull-out suture and the all-inside anchor techniques are defined for root fixation. Numerous suture-based fixators (knotless and classical suture anchors) are currently employed.
- We have used bovine knees, arthrotomy was performed proximal to the tibia, and the meniscal tissues were separated. The lateral meniscus was removed, and the PRMM was dissected. After this, a root repair was performed using either a suture or a knotless anchor[Group 1 (n=8) (classical suture anchor), Group 2 (n=8) (knotless suture anchor)] The specimens were first cycled at 5–20 N 100 times and then loaded until failure.
- There were no statistically significant differences between the groups, except in the elongation-to-failure test. The knotless anchor group (Group 2) had significantly fewer elongation compared to the knotted group.
- As we hypothesized, the knotless anchors possessed biomechanical properties similar to those of the knotted suture anchor. Thus, the results support our hypothesis that the knotless suture anchor technique provides superior biomechanical properties for meniscal elongation prevention under cyclic loading. Our study provides new insight into the biomechanical properties of knotted and knotless anchor types for other applications.

Clinical studies on MRT repairs are limited, and the optimal treatment strategy for MRTs is yet to be developed. Raustol et al. described an arthroscopic transosseous repair technique using an accessory posteromedial portal (12). DiFelice et al. first described an all-inside MRT repair with a suture anchor (13). The suture anchor repair does not need a bone tunnel; thus, it is advantageous for concomitant ligament reconstruction. A study by Engelsohn et al. confirmed meniscal root healing in one patient with arthrofibrosis by second-look arthroscopy, showing that meniscal root healing with magnetic resonance imaging took 9 months after surgery (14). Ahn et al. demonstrated the complete healing of a posterolateral MRT by second-look arthroscopy in 8 patients (15). Using second-look arthroscopy, Seo et al. reported clinical improvement without incomplete healing after a transtibial pullout suture repair in 11 patients (16). These studies suggest that a clear benefit for surgical repair over partial meniscectomy and that meniscal root repair restores meniscal function (16-20).

We hypothesized that the knotless anchor has biomechanical properties similar to those of the knotted suture anchor. Thus, we aimed to compare the biomechanical properties of the two anchors to determine their suitability for specific applications. To our knowledge, this is the first study that compares different anchor types and their biomechanical properties in meniscal root repairs.

Materials and Methods

We applied to the Tokat Gaziosmanpasa University Scientific Research and Project Board. After the board approval, we performed a pilot study as described below.

Specimen preparation

Two- to three-year-old bovine knees without prior injury were selected and kept at -20 °C. The weights of the bovines ranged between 150 kg and 300 kg. The specimens were thawed at room temperature for 12 hours. Arthrotomy was performed proximal to the tibia, and the meniscal tissues were separated. The lateral meniscus was removed, and the PRMM was dissected. After this, a root repair was performed using either a suture or a knotless anchor (Figure 1).

In Group 1 (n=8) (classical suture anchor), we performed a root fixation with a classical suture anchor using a FASTIN® RC dual channeled anchor (DePuy Mitek, Inc., MA), a two-passaged Mason-Allen suture configuration knotted six times with four strands in the meniscal tissue. The anchors were inserted perpendicular to

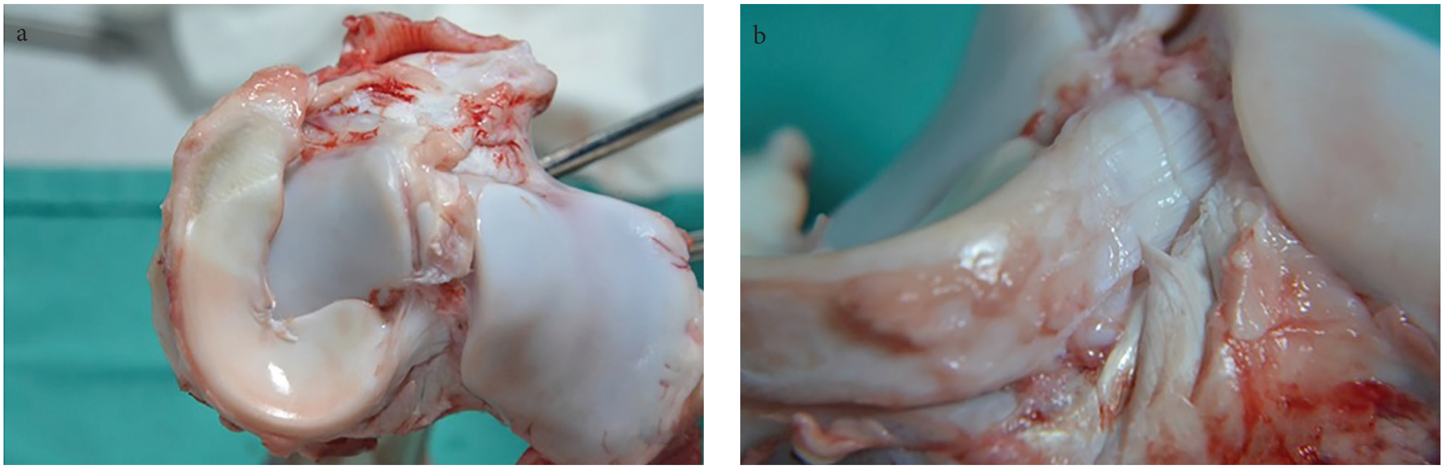

Figure 1. a, b. Dissected bovine knee (a); Close view of the posterior root ligament of the bovine meniscus (b)

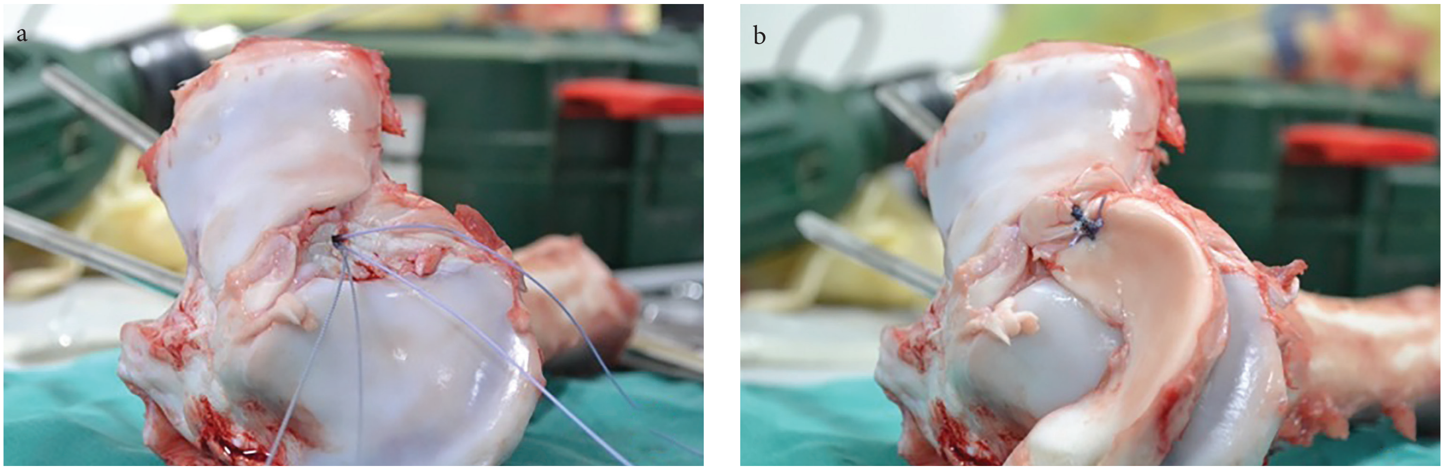

Figure 2. a, b. Knotted suture anchor insertion after preparation of the root ligament footprint (a) posterior root ligament fixation (b)

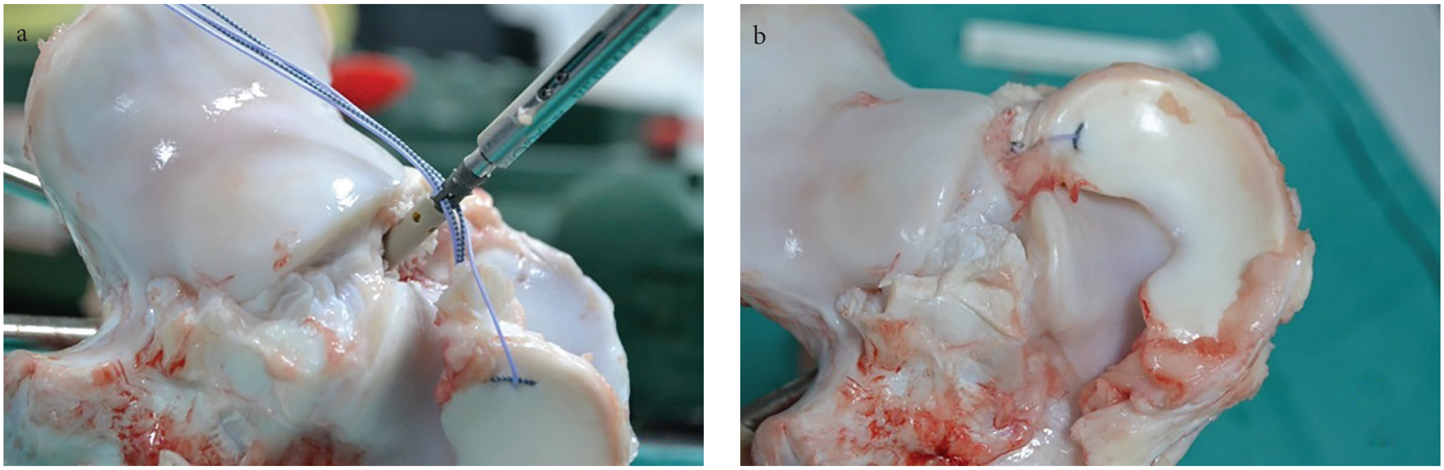

Figure 3. a, b. Knotless suture anchor insertion after preparation of the root ligament footprint (a) posterior root ligament fixation (b)

the posterior meniscal root footprint. The sutures were tensioned manually (Figure 2).

In Group 2 (n=8) (knotless suture anchor), we performed a root fixation with a knotless suture anchor (VERSALOK® Suture Anchor, DePuy Mitek, Inc., MA) after passing four strands through the meniscal tissue with a two-passaged Mason-Allen suture configuration, as was done in Group 1. The ends of the sutures were passed through the VERSALOK® Suture Anchor using the quick-load tab. The anchors were inserted perpendicular to the posterior meniscal root footprint after drilling with a 3.5 mm drill bit. The sutures were tensioned with a VERSALOK® Suture Anchor Deployment Gun (Figure 3).

Biomechanical testing

All specimens were tested at room temperature. The tibial sides of the specimens were connected to the fixed crosshead of the test machine with Schanz screws. The anterior portion of the medial meniscus was fixed to the moving crosshead of the test machine using a rough grip. The test machine was a Shimadzu AGS-X with a capacity of 5 kN and a video extensometer. The specimens were first cycled at 5–20 N 100 times and then loaded until failure (Figure 4). Equivalent stiffness, elongation, strength, and energy to failure were recorded separately (Table 1), and the distributions of variables by group were recorded (Table 2).

Statistical Analysis

Each descriptor for the two groups of anchors was represented as average±standard deviation. Averages were compared using the independent sample t-test. P values less than 0.05 were accepted as statistically significant. The software used was IBM SPSS Statistics 19 (SPSS Inc., an IBM Co., Somers, NY).

Results

Cyclic loading tests were performed at three stages. For the 0–20 N one-cycle test, the average equivalent stiffness values were found as 5.28±4.01 N/mm and 5.48±1.27 N/mm for Groups 1 and 2, respectively. The 5–20 N two-cycle test gave 8.29±3.23 N/mm and 8.66±2.02 N/mm, while the 5–20 N 100-cycle test, 8.59±2.96 N/mm and 10.18±2.31 N/mm for the knotted and knotless groups, respectively. The elongation values recorded for the knotted and knotless groups were 5.83±1.96 mm and 4.86±1.25 mm.

Based on the load-to-failure tests, failure forces of 237.83±114.21 N for the knotted group and 204.90±58.76 N for the knotless group were found. The failure test elongation values were 26.83±5.74 mm and 18.70±4.79 mm, and the failure energies were 3.87±2.85 J and 1.83±0.84 J for the knotted and knotless groups, respectively. There were no statistically significant differences between the groups, except in the elongation-to-failure test. The knotless an-

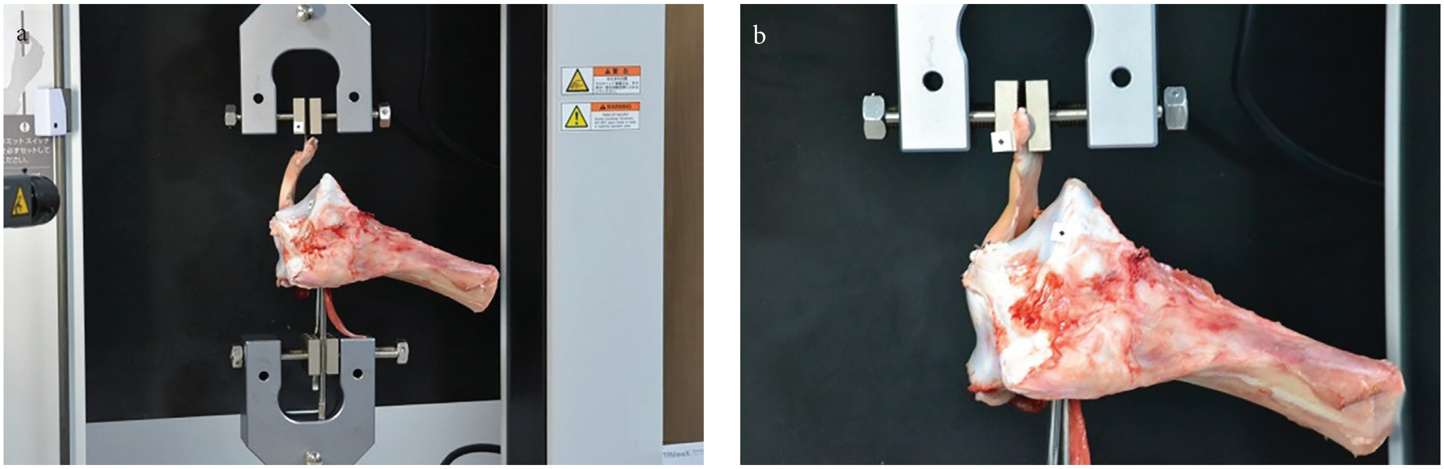

Figure 4. a, b. Attachment of specimens to the test machine using Schanz screws (a). Attachment of meniscal tissue to the moving crosshead of the test machine (b)

Table 1. Biomechanical test data

		Cyclic Experiments				Failure		
Type	**Number of Sample**	**Equivalent Stiffness Average [N/mm]**			**Elongation average [mm]**	**Force average [N]**	**Elongation average [mm]**	**Energy average [J]**
Knotted (Group 1)	8	5.28	8.29	8.59	5.83	237.83	26.83	3.87
	SD	4.01	3.23	2.96	1.93	114.21	5.74	2.85
		Cyclic Experiments				Failure		
Type	**Number of Sample**	**Equivalent Stiffness Average [N/mm]**			**Elongation average[mm]**	**Force average [N]**	**Elongation average [mm]**	**Energy average [J]**
Knotless (Group 2)	8	5.48	8.66	10.18	4.86	204.90	18.70	1.83
	SD	1.27	2.02	2.31	1.25	58.46	4.97	0.84
		0-20 N 1 Cycle	5-20 N 2 Cycles	5-20 N 100. Cycles	20 N (100. cycle -1. cycle)			
		Speed: 25 mm/min				Speed: 10 mm/min		

SD: standard deviation

Table 2. Distribution of Variables by Group

	GROUP				
	Knotted (n=8) (Group 1)		Knotless (n=8) (Group 2)		
	Average	SD	Average	SD	p
Cyclic Experiments - Equivalent Stiffness (N/mm) - 0-20 N 1 Cycle	5.28	4.01	5.48	1.27	0.892
Cyclic Experiments - Equivalent Stiffness (N/mm) - 5-20 N 2 Cycles	8.29	3.23	8.66	2.02	0.784
Cyclic Experiments - Equivalent Stiffness (N/mm) - 5-20 N 100 Cycles	8.59	2.96	10.18	2.31	0.250
Elongation (mm)	5.83	1.93	4.86	1.25	0.250
Failure - Force (N)	237.83	114.21	204.90	58.46	0.480
Failure - Elongation (mm)	26.83	5.74	18.70	4.97	0.009*
Failure - Energy (J)	3.87	2.85	1.83	0.84	0.087

Cyclic experiments were performed at a speed of 25 mm/min

p: Independent sample t-test

*Statistically significant ($p<0.05$)

chor group (Group 2) had significantly fewer elongation compared to the knotted group.

Discussion

As we hypothesized, the knotless anchors possessed biomechanical properties similar to those of the knotted suture anchor. Thus, the results support our hypothesis that the knotless suture anchor technique provides superior biomechanical properties for meniscal elongation prevention under cyclic loading. Except for the elongation under cyclic loading, no statistically significant differences were found between the two groups.

Since MRTs can lead to serious health problems, their repair is essential (7-9, 21). Root tear of the medial meniscus has become increasingly recognized, but relatively few reports have described different repair techniques and their biomechanical analyses. The posterior horn has an important role in maintaining circumferential hoop tension of the knee and preventing meniscal extrusion. A posterior meniscal tear predisposes to the development of knee osteoarthritis as much as a total meniscectomy (5, 10).

Two repair techniques are defined for meniscal root repairs, with numerous modifications: the all-inside repair and the pull-out repair (11, 22-26). Numerous studies have compared these two techniques, but the results are contradicting. Some authors have promoted the pull-out techniques (3, 18, 27), while others have argued that the pull-out technique has poor healing rates and is associated with progressive extrusion of the medial meniscus (16, 26). Biological factors and the biomechanical properties of the repair technique have important roles in meniscal healing. Feucht et al. reported biomechanical disadvantages of the pull-out repair technique (28). These disadvantages are associated with the long meniscus-suture construct between the anteromedial cortex of the tibia and the meniscal tissue. The long meniscus-suture construct might result in excessive motion during the early postoperative period and could possibly compromise meniscal healing. Other disadvantages of the pull-out technique are tunnel widening that might erode the suture structure before meniscal healing and difficulty in adjusting the suture tension because of the long tibial tunnel suture length (18). Despite these disadvantages, the transtibial pull-out suture technique provides progenitor stem cells from the tunnel to the knee and could promote meniscal healing (29, 30).

Comparisons between pull-out sutures and suture anchors receive attention for posterior meniscus root repairs. Other than the studies about repair suture materials, there is no data about the differences between suture anchor types. Knowing the advantages of using certain anchor subtypes may influence the success of meniscal root tear repair. With the use of modern suture passing devices, suture management is simpler for the knotless anchor when fixing the posterior medial meniscus root. After conventional suture anchoring, decreased working space could restrict passing suture material through the meniscal tissue.

Although there were no statistical differences between the two groups, the 5–20 N force 100-cycle average equivalent stiffness was higher for the knotless anchor group (10.18±2.31 N/mm) than for the knotted anchor group (8.59±2.96 N/mm). This result indicates that knotless anchors have a better stabilizing effect than knotted anchors even after 100 cyclic loadings, and this effect does not change after repetitive stress loading.

The elongation average was 5.83 mm for the knotted group and 4.86 mm for the knotless suture group. Although the difference is small, the knotless anchors have less average elongation, meaning that knotless anchors are superior to knotted anchors for preventing meniscal excursion during cyclic loading. That could offer an advantage for preventing meniscal extrusion *in vivo* prior to meniscal root healing.

The knotted anchors group had an average failure force (237.83±114.21 N) higher than that of the knotless group (204.90±58.76 N), indicating that knotted anchors are more resistant to failure than the knotless anchors, but the higher standard deviations for the knotted group (±114.21 N) point to higher variability of data and unpredictable behavior under the failure test. For this reason, this parameter was not statistically significant. The parameter that we used in the biomechanical load-to-failure test was energy. Even though it was not statistically different, the energy was higher in the knotted anchor group than in the knotless anchor group. Although it might suggest that knotted anchors are more resistant to failure, this is not necessarily true. Energy is calculated based on substitution and force parameters. The ideal implant that can mimic the native meniscal root should be resistant to not only force but also elongation. Less force-resistant and more flexible materials should absorb more energy, but due to higher elongation, they are considered ductile, so these kinds of materials are not ideal for fixation. On the other hand, extremely force-resistant and less ductile materials could withstand higher energy, but they are not ideal materials for meniscal root fixation because minimal movement is necessary for the recovery of native meniscal tissue mobility after the meniscal root healing. So, to determine the relationships between force and fixation quality, *in vivo* studies should be performed to observe the behavior of materials in biological environments.

One of the important limitations of our study is that the bovine knee does not fully simulate the human knee because of the size and structural differences between the two. Nevertheless, bovine knee joints are used for orthopedic research (31-34). Also, the gender of the bovines and sizes of specimens were disregarded. For the randomization of the study groups, we only recorded the age and weight intervals.

During the everyday motion of the knee, the meniscal tissue is exposed to multiple forces from different directions, such as shearing and compression, which were not simulated in our model. However, unidirectional loading on the specimens was applied parallel to the circumferential fibers of the PMMR. In addition, we did not design a control group that had intact meniscal roots. Finally, the strength of fixation of the posterior meniscal root is also associated with repair tension; we have not standardized the repair tension while knotting and locking our anchors. This limitation may also influence SD values.

In conclusion, knotless anchors have biomechanical properties similar to those of knotted anchors for preventing meniscal excursion. Moreover, due to their technical simplicity during arthroscopic surgery, knotless anchors can offer safe fixation of the meniscal root ligament. Our study provides new insight into the biomechanical properties of knotted and knotless anchor types for other applications. Further studies are necessary to discover a stronger, more biologic repair.

Ethics Committee Approval: Ethics committee approval was received for this study from Tokat Gaziosmanpasa University Scientific Research and Project Board.

Informed Consent: N/A.

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