ORIGINAL ARTICLE

Biomechanical Properties of Meniscal Repair Using a Suture Loop, All-Inside Suture Anchor-Based, and Inside-Out Vertical Mattress Suture: A Porcine Study

Punyawat Apiwatanakul, MD[1], Sermsak Sumanont, MD[1], Supanut Weraarchakul, MD[1], Pajeemas Kittipanya-ngam, MD[2], Artit Boonrod, MD[1]

[1] Department of Orthopedics, Faculty of Medicine, Khon Kaen University, Khon Kaen, Thailand; [2] Department of Rehabilitation Medicine, Khon Kaen University, Khon Kaen, Thailand

Background: Repairing the meniscus can be challenging in certain situations, such as when tears occur in the posterolateral corner of the knee or when there is insufficient tissue in the medial or lateral meniscus for traditional vertical mattress or commercially available suture anchor-based techniques. The all-inside suture loop technique could address these challenges; however, its biomechanical properties have not yet been compared to the standard techniques.

Objective: To compare the biomechanical properties of the meniscal repair techniques.

Materials and Methods: The present study was a controlled laboratory study (in-vitro). Thirty porcine menisci from 15 mature, fresh-frozen porcine knee joints without signs of degeneration were utilized. A vertical tear, parallel to the peripheral rim of the meniscus was created. Biomechanical properties were tested and compared among all-inside suture loop, all-inside vertical mattress using a suture anchor-based repair device, and the standard inside-out vertical mattress technique. A one-way ANOVA was used to assess differences among groups. Post-hoc Tukey's honest significance test was conducted for multiple comparisons.

Results: Load-to-failure was similar among the three groups for the three techniques, the suture loop 83.7±25.2 N versus anchor-based 92.7±41.8 N versus vertical mattress 66.8±17.1 N, (p=0.162). The suture loop and vertical mattress meniscal repair techniques exhibited greater stiffness than anchor-based technique (p=0.014 and 0.001, respectively). Additionally, the suture loop and vertical mattress techniques demonstrated less displacement than the anchor-based techniques (p<0.001 for both).

Conclusion: The all-inside suture loop technique demonstrated a comparable load-to-failure when compared to the standard vertical mattress and suture anchor-based technique. It also exhibited greater stiffness than the suture anchor-based technique. Considering the biomechanical properties, as well as the advantages of accommodating even small amounts of meniscal tissue remaining for repair with other techniques, avoiding injury to the popliteus tendon, and preventing knee joint stiffness, the suture loop technique could be a viable option for meniscal repair.

Keywords: Meniscus repair; All-inside suture loop; Biomechanical property

Received 29 March 2023 | Revised 5 September 2023 | Accepted 6 September 2023

J Med Assoc Thai 2023;106(9):875-81

Website: http://www.jmatonline.com

The meniscus is a crescent fibrocartilaginous tissue in the knee joint, lying between the femoral condyle and tibial plateau. It serves a crucial role in weight distribution and shock absorption[1-3]. Meniscus tears are commonly the result of sports injuries in young athletes or degenerative changes in older individuals, putting the knee at significant risk of degenerative arthritis[4]. Literature indicates that preserving the meniscus leads to better functional outcomes and reduced degenerative changes in knee joints[5-8]. The guiding principle of managing meniscal tears emphasizes the importance of meniscus preservation through repair, and various techniques have been proposed for this purpose. Approaches for meniscus repair include outside-in, inside-out, and all-inside techniques, depending on the location of the tear[9].

However, the repair of the meniscal tears located at the posterolateral corner presents challenges. The

Correspondence to:

Boonrod A.

Department of Orthopedics, Faculty of Medicine, Khon Kaen University, Khon Kaen 40002, Thailand.

Phone: +66-43-348360-8

Email: artibo@kku.ac.th

ORCID: 0000-0001-9014-243X

How to cite this article:

Apiwatanakul P, Sumanont S, Weraarchakul S, Kittipanya-ngam P, Boonrod A. Biomechanical Properties of Meniscal Repair Using a Suture Loop, All-Inside Suture Anchor-Based, and Inside-Out Vertical Mattress Suture: A Porcine Study. J Med Assoc Thai 2023;106:875-81.

DOI: 10.35755/jmedassocthai.2023.09.13891

challenges include difficulties in passing sutures through the hiatus and popliteus tendon, as well as potential complications such as irritation, stiffness, pain, and loss of motion[10]. There are also concerns about the risk of iatrogenic injury to the peroneal nerve and inferior lateral geniculate artery[11,12]. Strategies to mitigate these challenges, such as avoiding sutures over the popliteus tendon, have been recommended[13,14]. All-inside suture loop repair techniques have emerged as an alternative method. It aims to pass sutures through the popliteal hiatus posterior to the meniscus rim using a suture hook, thereby avoiding injury to the popliteus tendon[15,16].

In cases where a repairable meniscus tear exists in either the medial or lateral meniscus, but the tissue available for standard inside-out vertical mattress sutures or commercially available all-inside suture anchor-based techniques is insufficient, a suture loop repair technique may be utilized. This technique can incorporate the limited tissue without penetrating it. Despite the potential clinical utility of this method, its biomechanical properties have not been thoroughly explored.

This in vitro biomechanical study employs porcine meniscus models to compare the biomechanical properties of the all-inside suture loop repair technique with those of the all-inside vertical mattress repair using an anchor-based device (ULTRA FAST-FIX™, Smith & Nephew, Andover, Massachusetts) and the standard inside-out vertical mattress technique. The present study aimed to fill the knowledge gap regarding the biomechanical effectiveness of the all-inside suture loop technique. Given that previous studies have highlighted the risk of iatrogenic nerve injury and emphasized the need for safe zones during meniscal repair[17,18], the authors investigation aimed to refining meniscal repair techniques to minimize such risks. The authors hypothesized that the all-inside suture loop repair technique would exhibit comparable failure load and stiffness when compared to other established repair techniques.

Materials and Methods

Study design

An in vitro experimental study was designed to test the pullout strength of various meniscal repair techniques using a porcine meniscus model. Three different techniques were employed for repairing vertically longitudinally torn porcine menisci:

- The all-inside suture loop as suture loop.
- The all-inside vertical mattress technique using suture anchor-based repair device, ULTRA FAST-FIX™ as anchor-based.
- The standard inside-out vertical mattress as control.

Sample preparation

Thirty porcine menisci were obtained from 15 fresh-frozen mature porcine knee joints, all of which showed no signs of degeneration. These knee joints were sourced from a local butcher. The mean age of the animals was three years, and their mean body weight was 100 kg. The menisci were carefully dissected and wrapped in gauze soaked in normal saline, then stored at –20°C. They were thawed overnight at room temperature before testing. Each meniscus was randomly assigned to one of three repair techniques for the repair of longitudinal vertical tear of the meniscus with 10 samples in each group. A vertical tear, running parallel to the peripheral rim of the menisci from the anterior horn to the posterior horn, was created 5 mm away from the peripheral rim using a No.11 scalpel. The site chosen for suturing was the middle of the meniscus body.

Suturing techniques

Three different meniscal repair techniques were compared, the suture loop (Figure 1a), the anchor-based (Figure 1b), and the control (Figure 1c).

The all-inside suture loop technique involved passing a suture hook loaded with No.2 ULTRABRAID™ non-absorbable, ultra high molecular weight (UHMW) polyethylene co-braid suture (Smith & Nephew, Andover, Massachusetts) underneath the meniscus through the popliteal hiatus or the meniscotibial ligament. The upper leg of the suture was then retrieved, and arthroscopic knots were tied circumferentially around the meniscus[15].

The anchor-based group utilized the ULTRA FAST-FIX™ device (Smith & Nephew, Andover, Massachusetts) and contains two 5-mm polymerized poly-L-lactic acid suture T-bar anchors with a pre-tied self-sliding knot comprised of No.0 non-absorbable, UHMW polyethelene co-braid suture. The meniscal tear was repaired in a vertical mattress fashion, deploying two anchors, and advancing the pre-tied slip knot with a push-pull technique.

Inside-out vertical mattress technique, considering the gold-standard for meniscal repair in the posterior horn and body of the meniscus, and was used in the control group[14,19]. No.2 ULTRABRAID™ non-absorbable, UHMW polyethylene co-braid suture (Smith & Nephew, Andover, Massachusetts),

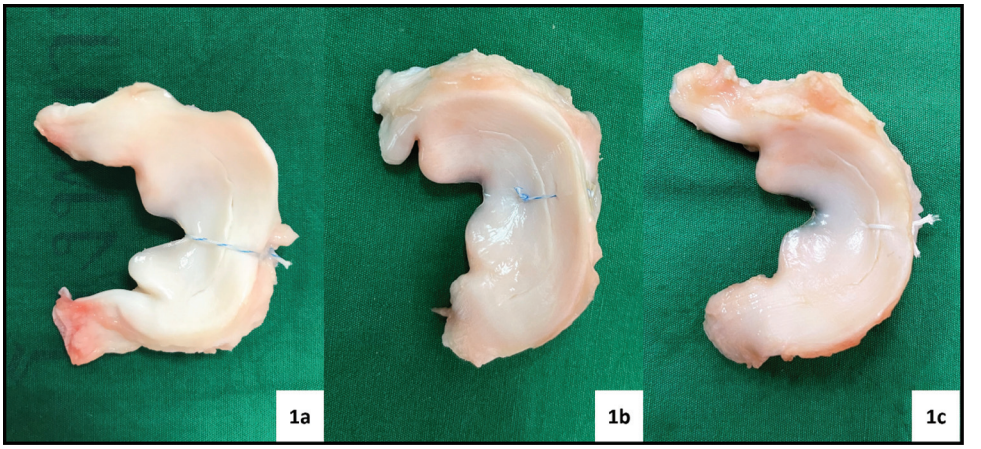

Figure 1. Meniscal repair techniques in this study include the suture loop (1a), anchor-based (1b), and inside-out control (1c) groups. The suture used in both the suture loop and inside-out group was No.2 non-absorbable UHMW polyethylene co-braid suture, available in either white and blue or solely white. For the Anchor-based group, a No.0 non-absorbable UHMW polyethylene co-braid suture was used, presented in white and blue. The color variations in the sutures have no impact on their properties.

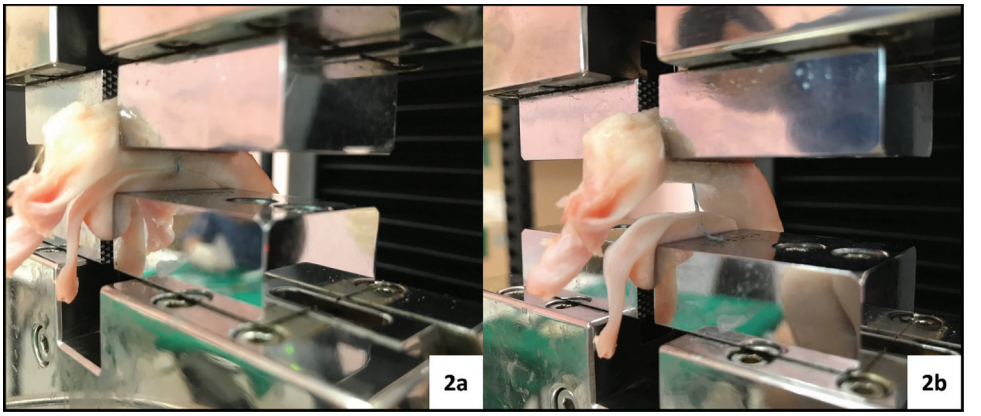

Figure 2. Meniscus was held with the clamp and mounted on a material testing machine (Instron 5944, Instron Corp., Norwood, MA) (2a), then loaded with tension in the long axis of the sutures (2b).

was passed into the meniscus on the capsular side on one end and into the inner meniscal fragment across the tear site into the capsular side of the meniscus on another end of the suture. The knot was tied on the back of the meniscus in the non-contacting surface area.

Biomechanics testing

Specimens were secured using a standard soft tissue pneumatic clamp mounted on a material testing machine (Instron 5944, Instron Corp., Norwood, MA). The specimen was then loaded with tension in the long axis of the sutures (Figure 2). The load to failure test was performed at a constant displacement rate of 12.5 mm/second. This displacement rate was used in prior studies evaluating the ultimate pullout strength of sutures and suture anchors[20-22]. The endpoint was the ultimate suture failure load. The time-load curves were generated using Instron Bluehill® 3 Software (Instron Corp., Norwood, MA). Mode of failure of each test such as loss of suture fixation, knot slippage, suture cut through, and anchor pull through, was recorded in a separate datasheet. Load at failure is the load value at the failure point; that is, where a sharp drop in the load occurs after the main part of deformation and energy absorption. Stiffness is a material's ability to return to its original form after being subjected to a force and calculated by using a force-displacement curve.

Statistical analysis

The Shapiro-Wilk test indicated that test variables followed normal distributions. Data were presented as either mean and standard deviation

(SD) for parametric data or median and interquartile range for non-parametric data. One-way analysis of variance (ANOVA) and post-hoc Tukey's honest significance test Tukey were used to evaluate group variable differences in biomechanical testing. A significance level of p-value less than 0.05 was set. Statistical analysis was conducted using IBM SPSS Statistics, version 26.0 (IBM Corp., Armonk, NY, USA).

Ethical approval

The present study has been reviewed and approved by the Institutional Animal Care and Use Committee of Khon Kaen University, in according with the Ethics of Animal Experimentation of National Research Council of Thailand (660201.2.11/336 (70)).

Results

Load to failure, displacement, and stiffness of each group were reported in mean and SD. The suture loop meniscal repair group demonstrated no statistically significant difference in ultimate failure load compared to the all-inside vertical mattress using anchor-based repair devices and the standard inside-out vertical mattress groups at 83.7±25.2 N versus 92.7±41.8 N versus 66.8±17.1 N (p=0.162). There were differences in displacement and stiffness among the groups, as shown in Figure 3 (p<0.001 and 0.001, respectively). Post-hoc analysis for displacement and stiffness was performed, and results are shown in Figure 3. The suture loop and inside-out vertical mattress groups had no statistically significant difference in stiffness (MD –1.8, 95% CI –6.49 to 2.72, p=0.573) and displacement (MD 0.96, 95% CI –0.76 to 2.68, p=0.362) after the ultimate load-to-failure test. However, when compared to the all-inside vertical mattress using anchor-base repair device, the suture loop and inside-out vertical mattress groups had statistically significant lower displacement (MD –3.56, 95% CI –5.28 to –18.4, p<0.001 and –4.52, 95% CI –6.24 to –2.80, p<0.001, respectively) and higher stiffness (MD 5.66, 95% CI 1.05 to 10.26, p=0.014 and 7.54, 95% CI 2.94 to 12.15, p=0.001, respectively).

The mode of failure during load-to-failure testing was mostly suture breakage. The suture loop repairs all failed due to suture failure with 10 failures (100%). Anchor-base repairs predominantly failed through suture failure for six (60%), followed by meniscus tissue cut-through for two (20%), and anchor pull-through for the other two (20%). Inside-out vertical mattress repairs predominantly failed through suture failure in eight cases (80%), followed by meniscus tissue cut-through for two cases (20%).

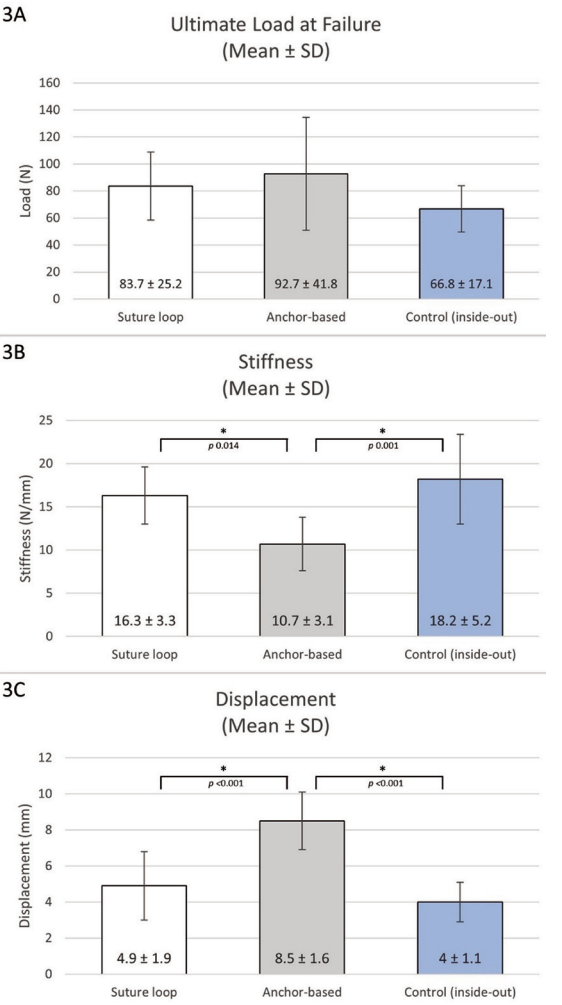

Figure 3. Mean ultimate load at failure (3A), stiffness (3B), and displacement (3C) of each group.

* Statistically significant difference from post-hoc analysis (p<0.05)

Discussion

The most important finding of the present study is that the suture loop meniscal repair technique demonstrated a comparable ultimate failure load to the standard inside-out vertical mattress and all-inside vertical mattress technique using anchor-based repair devices. The suture loop exhibited statistically significant lower displacement and higher stiffness when compared to all-inside vertical mattress technique.

To the best of the authors knowledge, this is the first study to tests the biomechanics properties

of suture loop meniscal repair technique using No.2 ULTRABRAID™ suture. Literature reported an average load to failure of 57.8 to 60.5 N for inside-out vertical mattress techniques using Ethibond 2-0[23,24], and 86.1 to 88.3 N for all-inside ULTRA FAST-FIX™ vertical mattress[25-27]. The reported average stiffness for ULTRA FAST-FIX™ was 4 to 25.8 N/mm[26-28]. Matthews et al. reported biomechanical properties of No.2 ULTRABRAID™ in a porcine model showing 88.05 N/mm of stiffness and an ultimate load to failure of 218.91 N[29]. The variation in the present study results might be attributed to differences in repair construct. A meta-analysis performed by Daniel et al. found that sutures exhibited higher load to failure and stiffness than devices[30]. However, the impact of diverse variables like suture size, repair technique, and device generation shoulder be considered when interpreting these disparities. Further research is necessary to fully understand the nuanced factors influencing these biomechanical outcomes.

Meniscus tissue cutting through and anchor pulling through were identified as modes of failure in inside-out vertical mattress repairs and anchor-based repairs, but not in the suture loop repair technique. This can be explained by the fact that the suture does not pass through the meniscal tissue in the suture loop repair technique. The predominant failure mode observed in our study was suture failure in 60% to 80%, consistent with the findings reported in other studies[23,31].

The all-inside suture loop technique can be applied to various meniscal tear locations, making it versatile for several types of tears. This technique has been proposed for repairing lateral meniscus tears at popliteal hiatus due to concern of risk of injuries to important nearby structures associated with other repair methods[15,16]. While easily applied using a suture passer, caution is advised to avoid over-tensioning the suture, which could result in meniscal deformity. In a clinical context, Fang et al. reported improved outcomes using this technique with a suture hook for treating horizontal tear of the lateral meniscus at popliteal hiatus in a 26-patient study[32].

Achieving anatomical reduction and repair of the meniscus through the inside-out and all-inside vertical mattress technique presents challenges. Non-anatomic repair can lead to excessive stretching and reduced lateral meniscus mobility over time[33]. Beyond lateral meniscus repairs, the suture loop repair technique can also be applied to the medial meniscus, particularly when remaining meniscal tissue is insufficient or in complex tears where standard repair techniques are unsuitable.

There are limitations to the present biomechanical study. First, intact porcine menisci were used instead of human menisci. However, using a porcine model eliminates variables like degenerative components from aged human donors. Compared to the human meniscus, porcine and ovine are most comparable in size[34]. Further study by Takroni et al. found that ovine menisci are more similar than porcine menisci to human tissues in terms of tissue volume and weight[35]. However, while no animal model is the gold standard for all aspects of meniscal research, several species have been used to successfully test specific hypotheses[36]. The porcine model is practical and commonly utilized in the study investigating meniscal biomechanics and repair techniques[29,37].

Second, the testing machine used in the present study was limited to a single ultimate loading test. Cyclic loading would offer a better physiological model for studying the biomechanical properties of various repair techniques[38]. Nonetheless, Seil et al. showed that loading to failure after cyclic loading exhibited similar failure strengths compared to single maximal loading[39].

Third, neither the capsule nor the meniscotibial ligament was included in the study model. This omission might differ from clinical practice where these structures are often incorporated with meniscus tissue. Lastly, the present sample size was small, but consistent. Further detailed study involving human menisci, cyclic loading, and larger sample sizes is necessary to refine the technique.

In summary, the all-inside suture loop meniscal repair technique offers potential advantages, including minimized tissue trauma, anatomy preservation, and versatility. However, it also has limitations related to technical proficiency and the need for more long-term data. While the present study has provided valuable insights into the biomechanical properties of the suture loop repair technique, further research involving human cadaveric meniscal tissue and clinical studies is needed.

Conclusion

The all-inside suture loop meniscal repair technique showed comparable pullout strength to the gold standard inside-out vertical mattress suturing technique and all-inside suture anchor-based vertical mattress meniscal repair technique for repairing vertical tear in the meniscus. Given its biomechanical properties and its advantages in avoiding injury to the popliteus tendon and preventing knee joint

stiffness, the all-inside suture loop technique should be considered as an option for treating meniscal tears.

What is already known on this topic?

Standard vertical mattress suture and commercially available all-inside suture anchor-based techniques are commonly used for meniscus repair. However, these techniques may result in subsequent complications when treating meniscal tears in the posterolateral corner of the knee[11,12].

What does this study add?

The all-inside suture loop meniscus repair technique offers biomechanical properties comparable to the standard inside-out vertical mattress and suture anchor-base technique. By avoiding injuries to structures located behind the posterolateral corner of the knee, this technique emerges as an option for treating meniscal tears.

Acknowledgement

The authors are deeply indebted to Kriengkrai Nabudda for his expert advice and suggestions regarding the machinery used in the laboratory. Authors are most thankful for Smith & Nephew Ltd., Thailand for providing instrumental support for the project.

Funding disclosure

The present study was granted by Faculty of Medicine, Khon Kaen University, Thailand (grant number, IN64137).

Conflicts of interest

None of the authors has received or will receive benefits for personal or professional use from a commercial party related directly or indirectly to the subject of this article. No benefit in any form has been or will be received from a commercial party related directly or indirectly to the subject of the present manuscript.

References

1. Flandry F, Hommel G. Normal anatomy and biomechanics of the knee. Sports Med Arthrosc Rev 2011;19:82-92.
2. Fox AJ, Bedi A, Rodeo SA. The basic science of human knee menisci: structure, composition, and function. Sports Health 2012;4:340-51.
3. Fox AJ, Wanivenhaus F, Burge AJ, Warren RF, Rodeo SA. The human meniscus: a review of anatomy, function, injury, and advances in treatment. Clin Anat 2015;28:269-87.
4. Farrow L. Arthroscopic management of meniscus tears at the popliteal hiatus. Oper Tech Sports Med 2018;26:251-5.
5. Eseonu KC, Neale J, Lyons A, Kluzek S. Are outcomes of acute meniscus root tear repair better than debridement or nonoperative management? A systematic review. Am J Sports Med 2022;50:3130-9.
6. Kopf S, Beaufils P, Hirschmann MT, Rotigliano N, Ollivier M, Pereira H, et al. Management of traumatic meniscus tears: the 2019 ESSKA meniscus consensus. Knee Surg Sports Traumatol Arthrosc 2020;28:1177-94.
7. Xu C, Zhao J. A meta-analysis comparing meniscal repair with meniscectomy in the treatment of meniscal tears: the more meniscus, the better outcome? Knee Surg Sports Traumatol Arthrosc 2015;23:164-70.
8. Lee WQ, Gan JZ, Lie DTT. Save the meniscus - Clinical outcomes of meniscectomy versus meniscal repair. J Orthop Surg (Hong Kong) 2019;27:2309499019849813.
9. Beaufils P, Pujol N. Meniscal repair: Technique. Orthop Traumatol Surg Res 2018;104:S137-45.
10. Ouanezar H, Blakeney WG, Latrobe C, Saithna A, Fernandes LR, Delaloye JR, et al. The popliteus tendon provides a safe and reliable location for all-inside meniscal repair device placement. Knee Surg Sports Traumatol Arthrosc 2018;26:3611-9.
11. Cuéllar A, Cuéllar R, Díaz Heredia J, Cuéllar A, García-Alonso I, Ruiz-Ibán MA. The all-inside meniscal repair technique has less risk of injury to the lateral geniculate artery than the inside-out repair technique when suturing the lateral meniscus. Knee Surg Sports Traumatol Arthrosc 2018;26:793-8.
12. Jurist KA, Greene PW, 3rd, Shirkhoda A. Peroneal nerve dysfunction as a complication of lateral meniscus repair: a case report and anatomic dissection. Arthroscopy 1989;5:141-7.
13. Uchida R, Mae T, Hiramatsu K, Iuchi R, Kinugasa K, Shino K, et al. Effects of suture site or penetration depth on anchor location in all-inside meniscal repair. Knee 2016;23:1024-8.
14. Nelson CG, Bonner KF. Inside-out meniscus repair. Arthrosc Tech 2013;2:e453-60.
15. Snyder RL, Jansson KA. Technical note: peripheral meniscus repairs anterior to the popliteal hiatus. Arthroscopy 2000;16:E19.
16. Thaunat M, Ingale PS, Vieira TD, Auboyneau G, Ghazi A, Sonnery-Cottet B. Posterolateral approach for all-inside arthroscopic lateral meniscus repair in athletes: technique and outcomes. Arch Orthop Trauma Surg 2021;141:1101-8.
17. Chuaychoosakoon C, Wuttimanop W, Tangjatsakow P, Charoenrattanawat S, Parinyakhup W, Boonriong T, et al. The danger zone for iatrogenic neurovascular injury in all-inside lateral meniscal repair in relation to the popliteal tendon: An MRI study. Orthop J Sports Med 2021;9:23259671211038397.
18. Chuaychoosakoon C, Boonsri P, Tanutit P,

Laohawiriyakamol T, Boonriong T, Parinyakhup W. The risk of iatrogenic peroneal nerve injury in lateral meniscal repair and safe zone to minimize the risk based on actual arthroscopic position: An MRI study. Am J Sports Med 2022;50:1858-66.
19. Pace JL, Inclan PM, Matava MJ. Inside-out medial meniscal repair: Improved surgical exposure with a sub-semimembranosus approach. Arthrosc Tech 2021;10:e507-17.
20. Boenisch UW, Faber KJ, Ciarelli M, Steadman JR, Arnoczky SP. Pull-out strength and stiffness of meniscal repair using absorbable arrows or Ti-Cron vertical and horizontal loop sutures. Am J Sports Med 1999;27:626-31.
21. Arnoczky SP, Lavagnino M. Tensile fixation strengths of absorbable meniscal repair devices as a function of hydrolysis time. An in vitro experimental study. Am J Sports Med 2001;29:118-23.
22. Herbort M, Siam S, Lenschow S, Petersen W, Zantop T. Strategies for repair of radial tears close to the meniscal rim--biomechanical analysis with a cyclic loading protocol. Am J Sports Med 2010;38:2281-7.
23. Fogerty S, Nazarian A, DeAngelis JP, Ramappa AJ, Valderrabano V, Rosso C. Cyclic and load-to-failure testing of inside-out ethibond sutures in a meniscal model. Sports Orthop Traumatol 2013;29:118-21.
24. Aşík M, Sener N. Failure strength of repair devices versus meniscus suturing techniques. Knee Surg Sports Traumatol Arthrosc 2002;10:25-9.
25. Lee YH, Nyland J, Burden R, Caborn DN. Repair of peripheral vertical meniscus lesions in porcine menisci: in vitro biomechanical testing of 3 different meniscus repair devices. Am J Sports Med 2013;41:1074-81.
26. Rosso C, Kovtun K, Dow W, McKenzie B, Nazarian A, DeAngelis JP, et al. Comparison of all-inside meniscal repair devices with matched inside-out suture repair. Am J Sports Med 2011;39:2634-9.
27. Mehta VM, Terry MA. Cyclic testing of 3 all-inside meniscal repair devices: a biomechanical analysis. Am J Sports Med 2009;37:2435-9.
28. Barber FA, Herbert MA, Schroeder FA, Aziz-Jacobo J, Sutker MJ. Biomechanical testing of new meniscal repair techniques containing ultra high-molecular weight polyethylene suture. Arthroscopy 2009;25:959-67.
29. Matthews JR, Wang J, Zhao J, Kluczynski MA, Bisson LJ. The influence of suture materials on the biomechanical behavior of suture-meniscal specimens: a comparative study in a porcine model. Knee Surg Relat Res 2020;32:42.
30. Buckland DM, Sadoghi P, Wimmer MD, Vavken P, Pagenstert GI, Valderrabano V, et al. Meta-analysis on biomechanical properties of meniscus repairs: are devices better than sutures? Knee Surg Sports Traumatol Arthrosc 2015;23:83-9.
31. Müller S, Schwenk T, de Wild M, Dimitriou D, Rosso C. Increased construct stiffness with meniscal repair sutures and devices increases the risk of cheese-wiring during biomechanical load-to-failure testing. Orthop J Sports Med 2021;9:23259671211015674.
32. Fang CH, Liu H, Di ZL, Zhang JH. Arthroscopic all-inside repair with suture hook for horizontal tear of the lateral meniscus at the popliteal hiatus region: a preliminary report. BMC Musculoskelet Disord 2020;21:52.
33. Aman ZS, DePhillipo NN, Storaci HW, Moatshe G, Chahla J, Engebretsen L, et al. Quantitative and qualitative assessment of posterolateral meniscal anatomy: Defining the popliteal hiatus, popliteomeniscal fascicles, and the lateral meniscotibial ligament. Am J Sports Med 2019;47:1797-803.
34. Proffen BL, McElfresh M, Fleming BC, Murray MM. A comparative anatomical study of the human knee and six animal species. Knee 2012;19:493-9.
35. Takroni T, Laouar L, Adesida A, Elliott JA, Jomha NM. Anatomical study: comparing the human, sheep and pig knee meniscus. J Exp Orthop 2016;3:35.
36. Arnoczky SP, Cook JL, Carter T, Turner AS. Translational models for studying meniscal repair and replacement: what they can and cannot tell us. Tissue Eng Part B Rev 2010;16:31-9.
37. Masoudi A, Beamer BS, Harlow ER, Manoukian OS, Walley KC, Hertz B, et al. Biomechanical evaluation of an all-inside suture-based device for repairing longitudinal meniscal tears. Arthroscopy 2015;31:428-34.
38. Becker R, Stärke C, Heymann M, Nebelung W. Biomechanical properties under cyclic loading of seven meniscus repair techniques. Clin Orthop Relat Res 2002;(400):236-45.
39. Seil R, Rupp S, Kohn DM. Cyclic testing of meniscal sutures. Arthroscopy 2000;16:505-10.