

Meniscal repair using large diameter horizontal sutures increases fixation strength: an in vitro study

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Abstract

Purpose The purpose of this study was to compare the mechanical characteristics of meniscal repair fixation using horizontal sutures and two different diameter sutures under submaximal cyclic and load to failure test conditions.

Method A 2-cm long anteroposterior vertical longitudinal incision was created in two groups of bovine medial menisci. Lesions were repaired using either #2-0 (Group 1), or #2 (Group 2) Fiberwire suture. Following repair, the lesion was extended through the posterior and anterior meniscal horns so that no tissue secured the repair site. Specimens underwent submaximal cyclic (5–50 N at 1 Hz for 500 cycles) and load to failure testing (5 mm/min crosshead speed) in a servo hydraulic device. Specimen

failure mode was verified by the primary investigator. An alpha level of $P < 0.05$ was selected to indicate statistical significance.

Results Group 2 displayed greater load at failure (132.1 ± 54.4 N) than Group 1 (91.9 ± 26.2 N) ($P = 0.02$). Group 2 also displayed greater stiffness (47.1 ± 8.3 N/mm) than Group 1 (38.5 ± 10.2 N/mm) ($P = 0.03$). The failure mode for all specimens was suture pull-through the meniscal tissue. Larger diameter suture provided superior mechanical meniscal fixation.

Conclusion If Horizontal suture would be used in meniscal repair, the most suitable larger diameter suture should be used.

Keywords Meniscus · Horizontal suture · Suture diameter

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Introduction

Over the last 50 years, surgeons have gained a greater appreciation for the menisci as integral components for normal knee function. The menisci provide shock absorption [22], tibiofemoral load transmission [13], facilitate lubrication with synovial fluid [11], and contribute to knee-joint stabilization [11]. When possible, meniscal repair following injury is preferable to meniscectomy to preserve the function of this important tissue [2]. Achieving secure arthroscopic meniscal repair is essential to avoid the need for restricted knee joint mobilization and lower extremity weight bearing during the early post-operative period [3]. Conventional inside-out meniscal repair techniques use either horizontal, vertical or oblique suture techniques. The superior ultimate strength provided by conventional vertical suturing using an inside-out technique has contributed

to its success and as such to be considered the gold standard for meniscal repair fixation [7]. Horizontal suture techniques although shown to be weaker during *in vitro* mechanical testing can secure a comparatively larger portion of meniscal tissue than vertical suture techniques because its suture alignment is parallel to the meniscal defect. Horizontal suture techniques can be more easily achieved arthroscopically when factors such as lesion type and location, and suture inclination and depth are equivalent [8]. The purpose of this study was to compare the mechanical characteristics of meniscal repair fixation of two different diameter horizontal sutures under submaximal cyclic, and load to failure test conditions. *In vitro* mechanical tests are only relevant for how a meniscus repair will perform before healing begins [15]. Therefore submaximal loads were used to evaluate horizontal suture meniscal repair fixation as they more closely simulate the loads experienced by the patient early post-surgery.

Materials and methods

Twenty-four bovine medial menisci with intact peripheral knee-joint capsules were harvested from 9 months old calves. Only intact medial menisci without macroscopic evidence of previous injury or degenerative changes were deemed acceptable for inclusion. Following harvesting, each meniscus was wrapped in a saline-soaked gauze sponge, and placed in a sealed plastic bag for storage at 6°C (21°F). Prior to use, all menisci were thawed in water at room temperature (23.9°C) for 12 h. Similar sized menisci were divided into two groups of twelve specimens each.

Meniscal lesion creation and repair

After thawing, a 2-cm long anteroposterior vertical longitudinal lesion was created with a #15 scalpel 3 mm from the outer edge of each meniscus. Following this, meniscus lesions were repaired using either #2-0 (Group 1), or #2 (Group 2) Fiberwire suture (Arthrex, Naples, FL, USA). All meniscal repairs were performed using two horizontal sutures initiated approximately 2–3 mm from the inner edge of the lesion, spaced approximately 5 mm apart using a total of five knots tied on the capsular side of the meniscus. The distance between the two horizontal suture strands and two horizontal sutures on the capsular side of the meniscal lesion was approximately 4 mm (Fig. 1). Following meniscal repair, the longitudinal lesion was extended completely through the posterior and anterior meniscal horns so that no tissue secured the repair, only the repair devices, representing a worst-case scenario. The primary investigator (YK) performed all meniscal lesion creation and repair procedures.



Fig. 1 Repaired meniscus with horizontal sutures and with extended lesion through anterior and posterior meniscal horns

In vitro mechanical testing

Following repair meniscal specimens were secured to a servo hydraulic device (MTS Mini Bionix II Axial/Torsional Servohydraulic Universal Testing Machine, Eden Prairie, MN, USA) using a pair of 1.2 mm diameter steel wire loops which were carefully positioned through each meniscus at 1 mm above and 1 mm below the repair site. Specimens were cyclically loaded between 5 and 50 N at 1 Hz for 500 cycles for conditioning prior to load-to-failure testing (Fig. 2). Load to failure tests were conducted at a 5 mm/min crosshead speed until the sutures were observed to be pulled through the meniscal tissue and the tensile load has diminished to nearly zero (Fig. 3). Data recording was carried out at 20 Hz during the whole test. All tests were conducted under force-control during cyclic loading and displacement control during failure loading. The servo hydraulic device was calibrated prior to testing



Fig. 2 Meniscal specimen undergoing load to failure testing

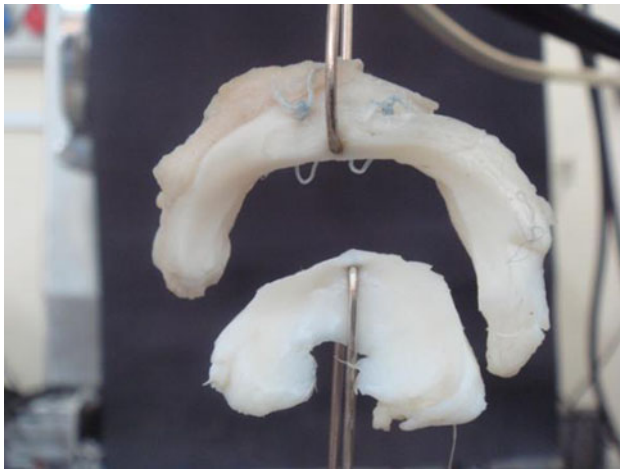


Fig. 3 Meniscal repair fixation failure



Fig. 4 Verification of suture pullout from meniscal repair site

using Peak-Valley-Phase control and a 400 N loadcell (ESIT, SPA 40 kg, S/N 836; ESIT Electronic Ltd., Istanbul, Turkey). Group 1 (#2-0 Fiberwire) and Group 2 (#2 Fiberwire) were compared for displacement during the cyclic loading test and for displacement, stiffness and load at failure during the load to failure test. Stiffness was calculated from the maximal and minimal sections of the linear portion of the load displacement curve. During and following biomechanical testing the primary investigator (YK) carefully inspected each specimen for failure mode (Fig. 4).

Statistical analysis

Wilk-Shapiro Tests confirmed that the data displayed a normal distribution, therefore parametric statistical analysis was performed. Independent sample *t* tests were used to evaluate group differences for displacement, load at failure,

and stiffness (SPSS ver. 14.0, Chicago, IL, USA). An alpha level of $P < 0.05$ was considered statistical significant.

Results

Displacement during cyclic testing was (mean \pm standard deviation) (3.5 ± 2.1 mm) for Group 1 and (2.5 ± 0.6 mm) for Group 2 “n.s”. Group 2 displayed greater load at failure (132.1 ± 54.4 N) than Group 1 (91.9 ± 26.2 N) ($P = 0.02$). Group 2 also displayed greater stiffness (47.1 ± 8.3 N/mm) than Group 1 (38.5 ± 10.2 N/mm) ($P = 0.03$). Displacement during load to failure testing was (11.1 ± 4.7 mm) for Group 1 and (10.8 ± 4.1 mm) for Group 2 “n.s”. All meniscal specimens displayed a suture pull-out failure mode.

Discussion

The most important finding of the present study was to how improving mechanical properties of horizontal suture techniques. To be effective a meniscal repair technique should approximate the torn tissue, resist gapping, and be able to withstand the forces associated with rehabilitation and activities of daily living that are initiated before the healing process is complete [9]. Most activities performed by patients over the initial postoperative weeks are repetitive with relatively low intensity loads. Therefore, mechanical test models that use repetitious, submaximal cyclic loading conditions provide a more valid simulation of these activities than ultimate load to failure tests [4, 12, 14]. Studies of meniscal repair fixation strength generally use the “worst-case scenario” condition of distraction loads applied perpendicular to the repair site. This loading condition however does not simulate in vivo meniscal loading [19, 23]. Several studies have been published which have examined the mechanical properties of various meniscal repair techniques [8, 10]. Kohn and Siebert [10] published one of the earliest studies on the mechanical strength of meniscal repair techniques. With a loading rate of 5 mm/min in excised cadaveric menisci [17–41 years old], meniscal repairs performed using vertical sutures produced a mean pullout strength of 105.4 N, which was significantly stronger than the 89.4 N mean pullout strength provided by meniscal repairs performed using horizontal sutures ($P = .01$). Therefore, they recommended that vertical sutures should be used for meniscal repair. Rimmer et al. [20] in using a cadaveric lateral meniscus model reported mean meniscal repair failure loads of 67 N when vertical sutures were used and 29.3 N when horizontal sutures were used. The meniscal repair failure mode for vertical sutures was suture rupture, while

horizontal sutures failed by an intact suture pulling through the central part of the repair [20]. The knee surgeon should consider the relative contributions of suture diameter and material properties to repair integrity when using a horizontal suture meniscal repair technique. While meniscal repair failure using vertical sutures tends to maximize the contributions of the suture material properties to construct integrity, this characteristic likely has little influence on the meniscal repair fixation strength provided by horizontal sutures. This is because during mechanical testing of horizontal suture meniscal repair techniques, constructs generally fail through suture meniscal pull-through, not suture rupture [16]. Post et al. [16] using a horizontal suture meniscal repair model and young porcine tissue reported insignificant load at failure test differences for constructs repairs using 1-PDS (73.81 ± 31.3 N), 0-PDS (66.1 ± 28.7 N) and for 2-0 Ethibond (59.7 ± 20.4 N). In our review of the literature we found that only the study of Post et al. [20] used different diameter suture for horizontal suture meniscal repair. Their results differ from ours, because they compared two different diameter suture made from same material but the diameter difference between both suture which was very close (0-PDS and 1-PDS) or relatively larger diameter difference (2-0 Ethibond and 1-PDS) but different material properties. In the literature all studies of horizontal suture meniscal repair fixation strength have used cadaveric, bovine, or porcine menisci. Although each of these tissues may enable sufficient representations time zero mechanical repair characteristics, none of these models match the physiological behaviour of the in vivo meniscus [6].

Our study is also limited in that bovine menisci and a non-physiological loading method was used. However, bovine menisci have been used in previous studies [1, 18]. The similar mechanical properties of bovine and human meniscus have been well described by Sweigart et al. [21]. Proctor et al. [17] and Boenisch et al. [5] suggested that they might serve as the ideal model to evaluate meniscal repair-device fixation integrity.

Fisher et al. [6] reported that the shear forces that tend to deform the repaired menisci in vivo differed considerably from most in vitro mechanical laboratory tests. Most meniscal injuries occur secondary to a torsional forces with a combined axial knee load. When both torsional and axial knee loads occur the menisci are subjected to combined shear and compressive forces. Force acting on the meniscus repair site can have both sagittal and coronal plane components resulting in oblique direction shear forces [23]. Our use of only a perpendicular distraction loading model is also a study limitation since it did not replicate the physiological shear or compression forces that occur in vivo. Despite these limitations our study revealed an important finding regarding horizontal suture use for

meniscal repair. Larger diameter sutures improve horizontal suture meniscal repair strength. Under in vivo conditions the menisci are generally subjected to compression forces which decrease the distance and increase the compression between individual collagen fibers. These additional compression forces tend to enhance the fixation characteristics of horizontal suture meniscal repair techniques. Since most in vitro mechanical test models that have compared vertical and horizontal suture meniscal repair fixation have not included compression forces, we believe that their validity and therefore their generalizability to the clinical scenario is limited. Although we found that menisci repaired using #2 diameter horizontal suture were mechanically superior in this in vitro study, clinically we prefer to use # 0 or #1 braided, late bioabsorbable suture material for horizontal suture meniscal repair. We have found this provides the best balance between the time zero fixation strength of larger diameter suture and biological meniscal lesion healing.

Conclusion

Larger diameter suture may increase pull-through resistance through meniscal collagen fibers thereby improving horizontal suture fixation. If Horizontal suture would be used in meniscal repair, the most suitable larger diameter suture should be used.

References

1. Asik M, Sener N (2002) Failure strength of repair devices versus meniscus suturing techniques. *Knee Surg Sports Traumatol Arthrosc* 10:25–29
2. Barber FA, Stone RG (1985) Meniscal repair. An arthroscopic technique. *J Bone Joint Surg Br* 7:39–41
3. Barber FA (1994) Accelerated rehabilitation for meniscus repairs. *Arthroscopy* 10:206–210
4. Becker R, Starke C, Heymann M, Nebelung W (2002) Biomechanical properties under cyclic loading of seven meniscus repair techniques. *Clin Orthop Relat Res* 400:236–245
5. Boenisch UW, Faber KJ, Ciarelli M et al (1999) Pull-out strength and stiffness of meniscal repair using absorbable arrows or Ti-Cron vertical and horizontal loop sutures. *Am J Sports Med* 27:626–631
6. Fisher SR, Markel DC, Koman JD, Atkinson TS (2002) Pull-out and shear failure strengths of arthroscopic meniscal repair systems. *Knee Surg Sports Traumatol Arthrosc* 10:294–299
7. Henning CE, Clark JR, Lynch MA et al (1988) Arthroscopic meniscus repair with a posterior incision. *Instr Course Lect* 37:209–221
8. Kocabay Y, Taser O, Nyland J, Doral MN, Demirhan M, Caborn DN, Sarban S (2006) Pullout strength of meniscal repair after cyclic loading: comparison of vertical, horizontal, and oblique suture techniques. *Knee Surg Sports Traumatol Arthrosc* 14:998–1003

9. Kocabey Y, Nyland J, Isbell WM, Caborn DNM (2004) Patient outcomes following T-Fix meniscal repair and a modifiable, progressive rehabilitation program, a retrospective study. *Arch Orthop Trauma Surg* 124:592–596
10. Kohn D, Siebert W (1989) Meniscus suture techniques: a comparative biomechanical cadaver study. *Arthroscopy* 5:324–332
11. Kurosawa H, Fukubayashi T, Nakajima H (1980) Load-bearing mode of the knee joint: physical behavior of the knee joint with or without menisci. *Clin Orthop Relat Res* 149:283–290
12. Lamprakis AA, Fortis AP, Kostopoulos V, Vlasis K (2009) Biomechanical testing of a shape memory alloy suture in a meniscal suture model. *Arthroscopy* 25:632–638
13. MacConaill MA (1950) The movements of bones and joints: the synovial fluid and its assistants. *J Bone Joint Surg Br* 32:244–252
14. McDermott ID, Richards SW, Hallam P et al (2003) A biomechanical study of four different meniscal repair systems, comparing pull-out strengths and gapping under cyclic loading. *Knee Surg Sports Traumatol Arthrosc* 11:23–29
15. Nyland J, Chang H, Kocabey Y, Nawab A, Brand J, Caborn DN (2008) A cyclic testing comparison of FasT-Fix and RapidLoc devices in human cadaveric meniscus. *Arch Orthop Trauma Surg* 128:489–494
16. Post WR, Akers SR, Kish V (1997) Load to failure of common meniscal repair techniques: effects of suture technique and suture material. *Arthroscopy* 13:731–736
17. Proctor CS, Schmidt MB, Whipple RR et al (1989) Material properties of the normal medial bovine meniscus. *J Orthop Res* 7:771–782
18. Rankin CC, Lintner DM, Noble PC et al (2002) A biomechanical analysis of meniscal repair techniques. *Am J Sports Med* 30:492–497
19. Richards DP, Barber FA, Herbert MA (2008) Meniscal tear biomechanics: loads across meniscal tears in human cadaveric knees. *Orthopedics* 31:347–350
20. Rimmer MG, Nawana NS, Keene GC, Pearcy MJ (1995) Failure strengths of different meniscal suturing techniques. *Arthroscopy* 11:146–150
21. Sweigart MA, Zhu CF, Burt DM, DeHoll PD, Agrawal CM, Clanton TO, Athanasiou KA (2004) Intraspecies and interspecies comparison of the compressive properties of the medial meniscus. *Ann Biomed Eng* 32:1569–1579
22. Voloshin AS, Wosk J (1983) Shock absorption of meniscectomized and painful knees: a comparative in vivo study. *J Biomed Eng* 5:157–161
23. Zantop T, Temmig K, Weimann A, Eggers KA, Raschke MJ, Petersen W (2005) Elongation and structural properties of meniscal repair using suture techniques in distraction and shear force scenarios. *Am J Sports Med* 34:799–805