The Knee xxx (2013) xxx–xxx

Contents lists available at SciVerse ScienceDirect

The Knee

The influence of suture material on the strength of horizontal mattress suture configuration for meniscus repair

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ARTICLE INFO

Article history:
Received 4 July 2012
Received in revised form 26 November 2012
Accepted 28 November 2012
Available online xxxx

Keywords:
Meniscus
Meniscal repair
Suture
Tensile load

ABSTRACT

Purpose: Comparison of the mechanical characteristics of meniscal repair fixation using horizontal sutures and six different sutures under submaximal cyclic and load to failure test conditions may aid physicians in selecting a suture type.
Methods: A 2-cm long anteroposterior vertical longitudinal incision was created in six groups of bovine medial menisci. Lesions were repaired using a No. 2 suture either composed of polyester or polyester and ultra high-molecular weight polyethylene (UHMWPE), or UHMWPE and polydioxanone or pure UHMWPE. Endpoints included ultimate failure load (N), pull-out stiffness (N/mm), pull-out displacement (mm), cyclic displacement (mm) after 100 cycles, after 500 cycles, and mode of failure.
Results: Polyester suture had lower ultimate load than all groups except the suture composed of polyester and UHMWPE ($P<.05$). Pure UHMWPE suture had higher ultimate failure load than sutures composed of either polyester or polyester plus UHMWPE ($P<.05$).
Predominant failure mode was suture cutting through the meniscus for the groups except for polyester suture which failed by suture rupture.
Conclusion: Under cyclic loading conditions in bovine meniscus, braided polyester suture fixation provided lower initial fixation strength than fixation with various high strength sutures composed of pure UHMWPE or a combination of absorbable monofilament polydioxanone and UHMWPE, except for combination of polyester and UHMWPE sutures.
Clinical relevance: Present study does not support the usage of the braided polyester sutures instead of high strength sutures composed either partially or totally of ultra-high molecular weight polyethylene for the horizontal suture configuration of meniscus repair.

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1. Introduction

Meniscectomy may result in premature knee osteoarthritis, and for this reason, torn meniscal tissue is repaired whenever possible [1]. An inside-out suture repair is the gold standard for meniscal repair [2,3]. Conventional inside-out meniscal repairs use either horizontal or vertical suture techniques. Horizontal sutures, although less biomechanically strong, have longer fixation of the suture, which tends to secure a greater meniscal tissue area than vertical suture techniques when other factors such as lesion type and location and suture inclination and depth are the same. Additionally, horizontal suture techniques can be more easily achieved arthroscopically when factors such as lesion type and location as well as suture inclination and depth are equivalent [4].

Ultra high-molecular weight polyethylene (UHMWPE) materials have influenced the load to failure and other biomechanical characteristics of sutures and suture anchors [5,6]. However, new high strength polyblend sutures have been reported to have a tendency to slip more than conventional braided polyester sutures [7,8]. Based on this, commonly used polyester sutures may be advantageous or an alternative for recent high strength sutures in horizontal mattress suture configuration for meniscus repair when suture failure mostly occurs due to sutures cutting through the meniscus rather than the rupture [4,9]. A recent biomechanical study reported that thicker No: 2 FiberWire sutures cut through the meniscus at higher loads than thinner No: 2-0 FiberWire for a horizontal repair of bovine meniscus tear model [9].

The hypothesis of the current study was that No: 2 Ethibond repair would result in less displacement when compared to No: 2 high strength

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http://dx.doi.org/10.1016/j.knee.2012.11.010

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sutures composed either partially or totally of ultra-high molecular weight polyethylene for the horizontal suture repair of a bovine meniscus tear model.

2. Materials and methods

Fifty-four bovine knees with intact peripheral knee-joint capsules were harvested from 9 month 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. Prior to use, all menisci were thawed in water at room temperature (24 °C) for 12 h. Similar sized menisci were divided into six groups of nine specimens each.

2.1. Specimen preparation

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 a No. 2 Ethibond (Ethicon, Somerville, NJ); No. 2 FiberWire (Arthrex, Naples, Fl); No. 2 UltraBraid (Smith & Nephew, Andover, MA); No. 2 MaxBraid (Arthrotek, Warsaw, IN); No. 2 Hi-Fi (ConMed Linvatec, Largo, FL); and No. 2 OrthoCord (DePuy-Mitek, Norwood, MA). All meniscal repairs were performed using one horizontal suture initiated approximately 2–3 mm from the inner edge of the lesion, using a total of five knots tied on the capsular side of the meniscus. The distance between the two horizontal suture strands and the 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 performed all meniscal lesion creation and repair procedures.

2.2. Biomechanical testing

Testing was conducted on a servohydraulic device (MTS Mini Bionix II Axial/Torsional Servohydraulic Universal Testing Machine, Eden Prairie, MN, USA) with a 5000-N maximum load. The applied stress was parallel to the axis of the repair system tested. Both segments of the repaired meniscus were held with metal clamps which were attached to the testing machine (Fig. 2). The displacement was measured by the distance traveled by the actuator of the material testing machine. Each specimen was cyclically loaded between 5 and 50 N at 1 Hz for 500 cycles for conditioning prior to load-to-failure testing (Fig. 3). Load to failure tests were conducted at a 5 mm/min crosshead speed until the sutures were observed to be cut through the meniscal tissue and the tensile load diminished to nearly zero. Data recording was performed at 20 Hz during the whole test.

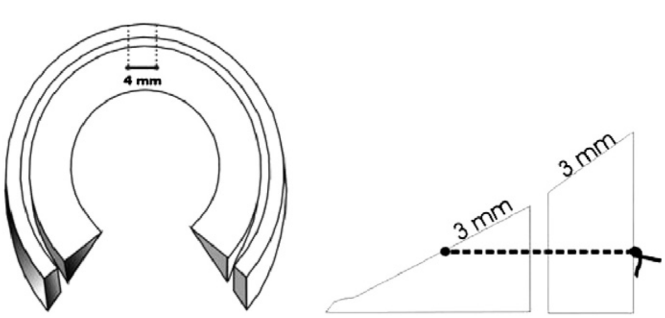

Fig. 1. Horizontal mattress suture repair technique.

Fig. 2. Biomechanical setup for isolated testing of tensile loading on the meniscal suture repair construct where both portions of the repaired meniscus are held with metal clamps attached to the testing machine.

Testing protocol was adapted from previous biomechanical studies [4,9–12] where the loading range was selected to simulate known medial meniscus loads during the application of forces equivalent to a clinical examination under both intact and deficient conditions of the anterior cruciate ligament [13]. The loading rate simulated the meniscal stresses that occur during early post-operative rehabilitation exercises and activities of daily living [11,14].

All tests were conducted under force-control during cyclic loading and displacement control during failure loading. The groups were compared for displacement during the cyclic loading (after 100 cycles, and 500 cycles) test and for displacement (mm), stiffness (N/mm) and load at failure (N). Pull-out stiffness was calculated from the slope of the load displacement curve using a best-fit line on the load versus displacement curve. The failure mode was recorded for each specimen.

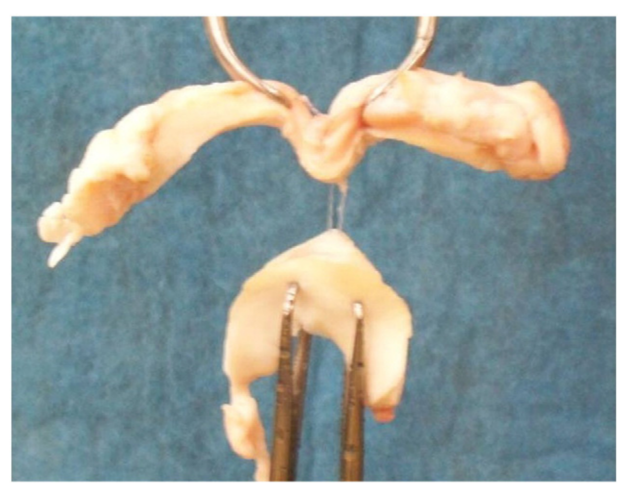

Fig. 3. Horizontal mattress suture repair failure due to suture cutting through the meniscus.

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2.3. Statistical analysis

Data analysis was performed using SPSS for Windows, version 11.5 (SPSS Inc., Chicago, IL, United States). Whether the distributions of continuous variables were normal or not was determined by the Shapiro Wilk test. The Levene test was used for the evaluation of homogeneity of variances. Data were reported as mean ± standard deviation or median (min–max), where applicable. The mean differences among groups were compared by One-Way ANOVA, otherwise, a Kruskal Wallis test was applied for the comparisons of the median values. When the *P* value from the One-Way ANOVA or Kruskal Wallis test statistics was statistically significant to know which group differs from which others, post hoc Tukey HSD or Conover's non-parametric multiple comparison tests were used. A *P*-value less than 0.05 was considered statistically significant. The primary aim of this study was to compare by means of differences in Load among groups. The total sample of 48 subjects (8 per groups) achieved 83% power to detect differences among the means versus the alternative of equal means using an F test with a 0.05 significance level. The size of the variation in the means is represented by their standard deviation, which is 26.94. The common standard deviation within a group is assumed to be 47.30. The sample size estimation was based on both the pilot study and clinical experience. The sample size estimation was performed by using NCSS and PASS 2000 software.

3. Results

The biomechanical test results are presented in Table 1. All specimens survived cyclic testing and were then loaded to failure. Mean cyclic displacement after 100 and 500 cycles were 1.3 ± 0.4 mm and 2.5 ± 0.8 mm which were not different between groups ($P<.05$). Ethibond had lower load to failure than all groups except FiberWire ($P<.05$). UltraBraid had a higher load to failure than Ethibond, FiberWire, or Hi-Fi ($P<.05$). Pull-out stiffness, displacements during, load to failure tests did not differ between the groups ($P>.05$). The predominant failure mode was due to sutures cutting through the meniscus tissue. Except for the Ethibond group, suture ruptures occurred in all 9 specimens.

4. Discussion

The main finding of this study was that recent high strength sutures composed of pure UHMWPE or a combination of absorbable monofilament polydioxanone (PDS; Ethicon) and UHMWPE, failed at higher loads than conventional braided polyester or combination of polyester and UHMWPE sutures with no difference between the two.

The load to failure testing displacement was the smallest for the Ethibond group. However, this has not been proven statistically because of the failure of the suture before slippage through the meniscus tissue.

Horizontal suture configurations for meniscus repair are reported to fail mostly due to suture cutting through the meniscus rather than the suture rupture [4,9]. Arthroscopic knots or tendon repairs performed with different suture types fail in different manners. Arthroscopic knots tied with polyester sutures were less likely to slip when compared to recent high strength sutures composed of UHMWPE [7,8]. In rotator cuff tendon repair models, polyester sutures were reported to fail because of suture rupture rather than the suture cutting through the tendon, which was the case for high strength sutures [15].

Based on this, the present study aimed to test the hypothesis that the suture holding load of the meniscus would be higher with the usage of No: 2 conventional polyester sutures compared to other recent No: 2 high strength sutures. Standardized diameter sutures were tested at the present study unlike the recent biomechanical tests [10,12,16–18].

Meniscus repair biomechanical tests use repetitious, submaximal cyclic loading conditions to provide a more valid simulation of the loads that the repaired meniscus is subjected in vivo [10,12,16,17]. It is unknown whether failure load is the most important parameter to test the strength of the meniscus repair. Stiffness is the ability of repair construct to resist gapping during loading. High stiffness and low displacement and/or gapping at the repair site are required to prevent delay of healing or failure of the repair [16].

Studies comparing various meniscus repair techniques or devices utilized No: 2-0 or 0 high strength sutures at horizontal or vertical mattress configurations [10,12,16,17]. Comparing these studies with the present study is extremely difficult since varying results, even for the same technique, have been reported. This was probably due to different sized sutures being tested, meniscus repair devices incorporating the anchors, implants in addition to the sutures and different testing protocols and conditions. The main outcomes of these studies are high strength suture fixation that is stronger than repair devices and horizontal repair tends to fail when sutures cut through the meniscus while vertical configuration tends to fail because of suture rupture [4,9,10,12,16–18].

It is still unknown just how strong a meniscal repair needs to be. The level at which this threshold occurs is unknown and may differ depending on the aggressiveness of early rehabilitation and whether or not early weight-bearing is allowed. Meniscal healing takes time, and any repair technique should accurately and securely approximate the tear edges to allow healing and, at the same time, be strong enough to protect the healing tear from any shear forces or daily activities until healing is complete [19].

Previous in vitro studies have shown that the meniscal repair site experiences loads of only up to 10 N [20]. Becker et al. [21] reported that distraction forces were not the primary factor compromising the mechanical stability of meniscal repair constructs. They concluded that other factors (eg, shear forces) may be considered as a greater risk factor for jeopardizing the meniscal repair integrity until healing has occurred. However, unpredictable loading of the knee within the rehabilitation period by undesired squatting, pivoting or twisting motions may cause deleterious distraction at the repair site [22]. Therefore, we have chosen the described distraction loading pattern to

Table 1
Average load to failure (N), stiffness (N/mm), displacement (mm) (± standard deviation) values and failure modes of the suture groups tested (Ultra high-molecular weight polyethylene 'UHMWPE', PDS 'polydioxanone').

	Group 1 (Ethibond)	Group 2 (FiberWire)	Group 3 (MaxBraid)	Group 4 (UltraBraid)	Group 5 (OrthoCord)	Group 6 (Hi-Fi)
Material (manufacturer)	Polyester (Ethicon, Somerville, NJ)	Polyester + UHMWPE (Arthrex, Naples, Fl)	UHMWPE (Arthrotek, Warsaw, IN)	UHMWPE (Smith & Nephew, Andover, MA)	PDS + UHMWPE (DePuy-Mitek, Norwood, MA)	UHMWPE (ConMed Linvatec, Largo, FL)
Failure load (N)	127.7 (± 15.3)	148.1(± 35.6)	169.0 (± 42.6)	187.6 (± 28.8)	167.2 (± 43.3)	159.8 (± 68.7)
Stiffness (N/mm)	12.2 (± 2.7)	11.9 (± 5.9)	12.9 (± 4.8)	11.4 (± 3.0)	12.9 (± 4.7)	13.9 (± 4.8)
Displacement (mm)						
cyclic testing						
(0–100 cycles)	1.2 (± 0.3)	1.1 (± 0.2)	1.5 (± 0.4)	1.5 (± 0.6)	1.1 (± 0.4)	1.5 (± 0.5)
(0–500 cycles)	2.3 (± 0.6)	2.2 (± 0.5)	2.8 (± 0.6)	2.9 (± 1.1)	2.2 (± 0.7)	2.8 (± 1.1)
Load to failure	10.0 (± 1.8)	13.3 (± 3.5)	12.5 (± 3.3)	15.1 (± 2.2)	13.4 (± 4.4)	12.7 (± 4.1)
Failure mode						
Suture rupture	9	1	1	1	2	1
Suture cut through	0	8	8	8	7	8

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simulate this worst-case scenario as well as because of the good comparability of our setup to several existing biomechanical in vitro studies of meniscal repair devices [10,12,16,17].

Depending on the above-mentioned, it is not possible to correlate load to failure values to clinical outcomes directly. Conventional polyester sutures, unlike other suture types, failed because of suture rupture and resulted in similar failure loads with FiberWire, which failed due to sutures cutting through the meniscus. This could also be interpreted to mean that when choosing a suture type for horizontal mattress configuration meniscus repair, commonly used polyester suture materials may not always be a bad option.

This study has some limitations. It is a time 0 biomechanical study, which did not evaluate the behavior of meniscus repair over time and only addressed the initial security of the construct. The specimens were tested perpendicular to the tear. This test construct cannot be directly compared with the in vivo situation. Meniscal loading in the human knee is much more complex and involves a large component of shear forces and compressive forces, subjecting the meniscus radial, circumferential tensile stresses which were not represented in this model in which a sole distraction force was used [19,23].

Another limitation might be the use of bovine menisci. However, mechanical properties of the bovine meniscus approximately resemble the properties of the human meniscus [24]. Therefore, we believe this limitation can be advantageous compared with the alternative of cadaveric human menisci obtained from elderly donors with degenerative alterations [18].

A recent biomechanical study reported higher pull-out loads and stiffness with the No: 2 FiberWire suture compared to the No: 2-0 FiberWire horizontal mattress suture fixation [9]. The present study aimed to find the suture holding capacity of the meniscus for different suture types excluding the failure mode of suture ruptures, which gives the strength of the suture instead. Additionally, in previous biomechanical studies, suture rupture was reported to occur in horizontal mattress configurations with No: 2-0 Ethibond or vertical mattress configurations with No: 2 Ethibond [25,26].

It was not our aim to comment on the clinical outcomes of any meniscal repair technique but rather to provide a biomechanical comparison of several commonly used suture types as they currently exist. This study does not support the usage of commonly used Ethibond sutures for horizontal mattress configuration over more recent high strength sutures depending on the cyclic load, failure load testings except for the FiberWire which failed at similar loads. Pure UHMWPE sutures and sutures composed of PDS and UHMWPE seem to be advantageous with higher suture cut-through loads than either polyester or a combination of polyester and UHMWPE sutures.

Present study does not support the hypothesis that No: 2 Ethibond repair would result in less displacement when compared to No: 2 high strength sutures composed either partially or totally of ultra-high molecular weight polyethylene for the horizontal suture repair of a bovine meniscus tear model.

5. Conflict of interest

None.

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Please cite this article as: Hapa O, et al, The influence of suture material on the strength of horizontal mattress suture configuration for meniscus repair, Knee (2013), http://dx.doi.org/10.1016/j.knee.2012.11.010