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ORIGINAL STUDY

Open meniscus repair in full and partial horizontal meniscal lesions : a biomechanical cadaver study

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Horizontal meniscal tears are often treated by partial meniscectomy. Some clinical studies have shown successful repair. The purpose of this study was to show that axial loading causes less horizontal displacement in partial than in total horizontal lesions and that suture of those lesions prevents horizontal displacement.
Forty menisci were tested : sutured partial horizontal lesions (ten), sutured total horizontal lesions (ten) and matched unsutured control groups (ten each). Samples were put in a custom made fixation device. 1000 cycles with axial loading, simulating partial weight-bearing of 15kg, were applied. Displacement was measured and construct stiffness was calculated.
No suture failure or pullout occurred. Horizontal displacement was insignificantly lower in partial then in full lesions as well as in sutured samples than in the control groups.
Horizontal displacement is low in both sutured and unsutured menisci in our test setting. Further studies with higher loads are required.

Key words : Meniscus ; Meniscus tear ; Cleavage lesion ; Meniscus repair ; Knee.

INTRODUCTION

Meniscal injuries are the most frequent pathology to the knee joint *(17)*. Fairbank revealed the importance of meniscal function in 1948. He reported the development of osteoarthritic changes in 107 patients after undergoing total meniscectomy *(9)*. The extent of resection is related to the radiologic graduation of osteoarthritis *(8,25)*. Anatomical studies have shown that healing after meniscal repair depends on tear location. Cooper described three zones with different blood supply : the outer third so called "red-red zone", the middle third "red-white zone" and the inner third "white-zone". The clinical relevance is that the more peripheral the meniscal lesion the better the healing potential after repair *(6)*. Horizontal tears divide the meniscus in two laminae and reach frequently into the inner third "white-zone" *(12)*. Until today there is no consensus in treatment of those horizontal lesions

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(13). Repair is often disregarded in favour of partial meniscectomy *(4,13,15)*. However, favorable results after repair of those lesions have been reported *(3,20)*. To our knowledge, there is no study available that has investigated the biomechanical performance of a suture in horizontal meniscal lesions. The purpose of this biomechanical study was to compare the effect of cyclic loading on suture displacement in partial and full horizontal meniscal lesions. The use of bovine menisci was owing to the difficulty of obtaining an adequate number of human samples. The hypothesis of the present study is that suture of partial tear patterns would withstand cyclic loading better than a full tear and that partial meniscal lesions would show superior results concerning displacement and construct stiffness.

MATERIALS AND METHODS

Preparation and repair

Fifty bovine menisci were harvested immediately after slaughter and fresh frozen at -20°C. Five menisci had to be ruled out due to pre-existing tears. Four groups were formed. The first two groups consisted of ten each matched paired menisci (five medial and lateral each). Group A contained the partial artificial horizontal lesion (20mm length, 10mm depth), group B the total artificial horizontal lesion (20mm length, full width tear). Partial lesions passed through the red-white zone while full lesions also passed through the white-white zone. Lesions were set in the intermedial part by the author (F.W.) after thawing specimen in saline soaked gaze at room temperature using a carbon steel number 20 surgical blade (FA Swann-Morton, Sheffield, England). Two vertical sutures were performed in the fashion shown in Fig 1, using 2-0 Vicryl plus sutures (FA Ethicon, Somerville, NJ, United States). Corresponding control groups C and D without suturing were formed by dividing twenty menisci in matched pairs into groups as mentioned above : Group C contained the partial artificial horizontal lesion (20 mm length, 10mm depth) and group D contained the total artificial horizontal lesion (20 mm length, full width tear). Additionally, five untreated menisci served as a control group for

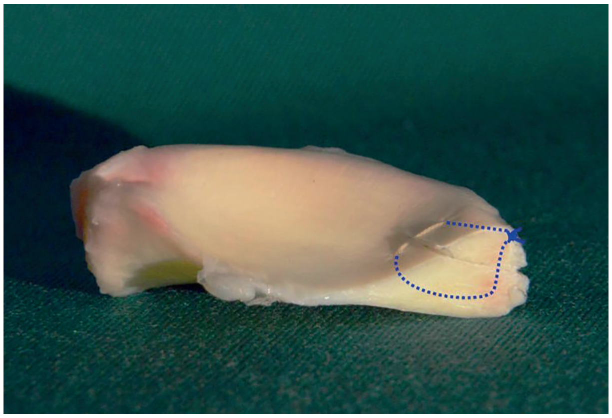

Fig. 1. — Suture pattern: A sample cut in the intermedial section, a full tear was set. The extrameniscal part of the suture can be seen with the blue dotted line representing the intramensical course of the suture.

construct stiffness. Samples were kept moist using saline solution spray during the whole experiment in an established procedure *(28)*.

Test setting

Samples were glued (Loctite 454, Henkel & Cie AG, 4133 Pratteln, Switzerland) on a Sawbone block and put in a custom-made, fully constrained fixation device. A steel sphere with a diameter of 40mm was used representing a simplified femoral condyle. This setup allowed the stamp to be positioned just above the center of the meniscus, which represents the worst-case-load. Ideally, an adjustable angle between the Sawbone block and the compressing axis of the testing machine created an inclined plane, so that the applied stamp force was partially transformed into a shear force. To mimic physiological loading during gait the inclination was set to 7° resulting in aFShear to FCompression ratio of 0.4/3 *(16)*. A body-weight of 80.3 kilograms was used for load calculation *(7)*. Muscular strength was disregarded as a partial weight-bearing scenario was tested. The weight of shank and foot was estimated as 6.5% of body-weight and subsequently left out of load calculation *(18)*. Consequently, the magnitude of the resulting force on a single meniscus was calculated to be 50N. Loading was performed using a universal testing machine (Zwick 1456, Zwick GmbH, Ulm, Germany), equipped with a 1kN load

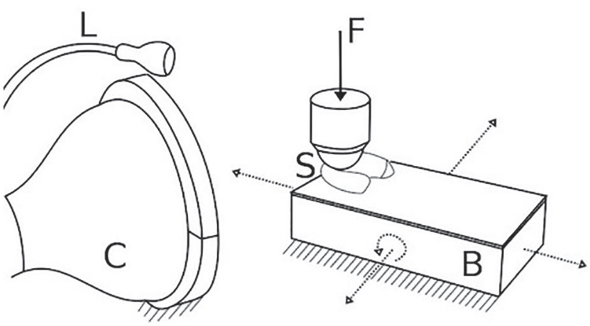

Fig 2. — Test setting. Specimen (C) is glued on a sawbone block (B). The block can be translated horizontally (dotted lines) to align the specimen below the force-axis (F) of the universal testing machine. To simulate shear forces, the block can be tilted. Telecentric camera (C) and light source (L) measure displacement of specimens area of interest.

cell (Zwick/Roell) (Fig 2). Thousand cycles from 0 - 50N were applied, simulating partial weight-bearing of 15kg (according to the local aftertreatment protocol) at a rate of 0.5 Hz. Load-displacement was recorded using TestXpert 10 software (Zwick GmbH). Further, high-resolution images were taken from the meniscal base to analyse displacement using telecentric lens (0.28 LARGE FORMAT, F-MOUNT, Edmund Optics, Germany), mounted to a digital camera (IDS UI-358-C-HQ, IDS Imaging Development Systems GmbH, Germany) and IDS Camera Software Manager software. Horizontal and vertical displacement between the superior margin of the inferior leaf and the inferior margin of the superior leaf was measured before cycle 0 and after cycle 1000, both with and without load of 50N. To prevent incorrect measurement due to sample slippage, all samples were marked with graphite powder. Displacement was measured using the same graphite marking as a reference point. Measurement was made using ImageJ, Version 1.49 (National Institutes of Health) with a pixel selection accuracy of ± 0.078mm. Construct stiffness was calculated for all tested specimen and compared to five native menisci by measuring the slope of the load-displacement curves which was recorded by the testing machine.

Load to failure testing was planned. However, while testing the first five samples after cyclic loading, each time the same technical failure occurred : all samples came off the sawbone block with increasing load. Hence load to failure testing had to be skipped.

Statistical Analysis

Analysis was made using Prism 6 (Graphpad) software. For horizontal and vertical displacement, a non-parametric, two-tailed unpaired Mann-Whitney-Test was performed.

Construct stiffness was calculated from load-displacement curves for the median of the cycles 10 to 300, 300 to 600 and 600 to 1000.

RESULTS

One sample of the suture group and one sample of the control group had to be ruled out due to technical failure while being tested (separation of the sawbone block during load application). No suture failure occurred after cycling in the suture

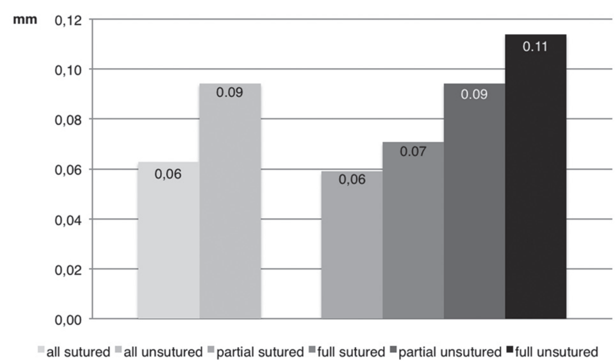

Fig 3a. — Median horizontal displacement in millimeters in all measured groups.

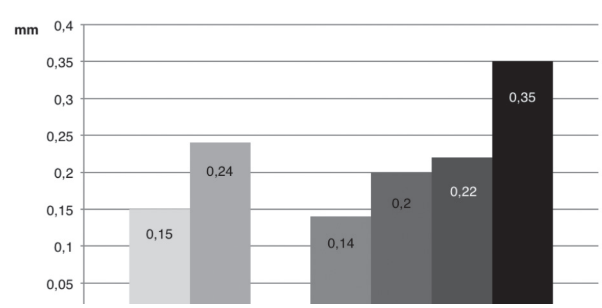

Fig 3b. — Median vertical displacement in millimeters in all measured groups.

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Table 1. — Comparison (Mann-Whitney-Test) between all sutured and all unsutured menisci und subgroup analysis shows no statistically significant difference in horizontal displacement.

Tested groups	p-value
All tears sutured vs all tears unsutured	0.1
Partial tear sutured vs. partial tear unsutured	0.22
Full tear sutured vs. full tear unsutured	0.51
Partial tear unsutured vs. full tear unsutured	0.46
Partial tear sutured vs. full tear sutured	0.22

Table 2. — Comparison (Mann-Whitney-Test) between all sutured and all unsutured menisci und subgroup analysis shows no statistically significant difference in vertical displacement.

Tested groups	p-value
All tears sutured vs all tears unsutured	0.34
Partial tear sutured vs. partial tear unsutured	0.2
Full tear sutured vs. full tear unsutured	0.84
Partial tear unsutured vs. full tear unsutured	0.35
Partial tear sutured vs. full tear sutured	0.59

groups. Moreover, no suture pullout happened. Median horizontal and vertical displacement increased slightly in all measured groups (Fig 3a and 3b). Sutured menisci showed less horizontal and vertical displacement than unsutured. In the subgroups, partial tears showed less displacement than full tears in both sutured and unsutured groups. None of these observations however was statistically significant (Table 1 and 2). Construct stiffness increased insignificantly under repeated use.

DISCUSSION

The most important finding of the present study is that no suture failure occurred after cyclic loading corresponding a partial weight bearing aftertreatment protocol. Therapy of meniscal injuries is complex and consists of both nonoperative and operative methods *(10,14,17,23)*. When compared to partial meniscectomy, preserving meniscus tissue by performing repair has been reported to have superior results concerning function, return to sports and cartilage protection *(5,19,21,22,26)*.

While there are established treatment methods for longitudinal vertical tears *(14)*, consensus is lacking for treatment of horizontal tears *(1,13,14)*. Horizontal meniscal tears were described by Biedert in 1993 as an intrasubstance tear *(2)*. Those tears divide the meniscus into a superior and an inferior lamina and reach frequently into the avascular zone *(13)*. In their systematic review of literature, Kurzweil et al. described a preference of partial meniscectomy with repair rarely being performed *(13)*. Operative difficulties performing the repair *(4,14)*, potential of suture failure caused by shear forces between the superior and inferior leaves *(13)* and poor healing rates were among the reported rationales for abandonment of repair. However, there is evidence of successful open repair of horizontal meniscal lesions *(13)*. Pujol et al. reported a series of open repair after arthroscopy in 30 knees in 28 patients *(20)*. Treatment was satisfying for 16 of 19 patients available for follow-up after a median of 40 months with four patients having clinical failure. The latter underwent partial meniscectomy. In a small series of nine patients, Kamimura combined a vertical suture with application of an exogenous fibrin clot and reported a 100% healing rate after performing repeat arthroscopy 12 months after surgery *(12)*. Biedert compared different treatment options in a randomized trial : 9 of 10 patients treated with suture had a normal or nearly normal final clinical and imaging evaluation at a follow-up of 26.5 months, while all of the 11 patients treated with partial meniscectomy showed normal findings *(3)*. Based on these results, Biedert concluded that intrasubstance meniscal lesions can be treated best by partial meniscectomy but he indicated that mid- to longterm results in patients treated with suture repair might be superior to the former *(3)*.

Preserving meniscal tissue by suture might provide superior longterm results regarding development of osteoarthritis. Clinical studies have shown that suture of those lesions can successfully be performed via a mini open approach *(20,27)*. A success rate of 76% in 47 patients after 70 months of follow up *(27)* and 84% after 40 months of follow up *(20)* argues against poor healing potential.

Biomechanical testing of horizontal meniscal lesions is critical to clear the assumption of suture failure due to shear forces between superior and inferior leaves. In the present study, 0 of 19 sutured menisci failed after cyclic loading. No suture pullout occurred. Horizontal displacement was surprisingly low. Partial tears showed insignificantly less horizontal displacement than full tears both in the sutured and in the unsutured group. Presence of a suture did not have statistically significant influence on vertical displacement after cyclic loading.

Construct stiffness increased with the amount of cycles in all samples and with the presence of a suture. Loss of elasticity because of drying-out explains the increase in all samples while material property of the used wire explains the increase in stiffness in the suture groups. Type of tear showed a trend for lesser increase in stiffness for partial tears while this result was statistically not significant. This finding is explained by the subordinate influence of the wire on construct stiffness when meniscus tissue is partially intact. In general, the downright stiffness values were similar in the different groups.

These findings show that after undergoing repetitive axial loading and shear stress, a suture is able to hold both meniscal leafs in place in a simplified setting. Thus, the suture seems to provide enough mechanical stability for the sutured meniscus to heal.

Based on our results, fear of suture failure due to shear forces seems to be unjustified. But as the horizontal displacement was only slightly lower in the sutured menisci than in the unsutured controls, one has to question the need of an operative intervention after all.

It is important to notice, however, that these results have materialized under a simplified setting of our local aftertreatment protocol : 15 kilograms of partial-weight bearing with the use of crutches. Any aftertreatment exceeding this weight cannot be supported by the present study.

The simplified setting has led to several limitations.

The use of bovine menisci disallows to one-to-one transfer of the results on human menisci – a fact that has been research topic and known limitation to previous biomechanical meniscus studies *(11)*. Bovine menisci are significantly larger and more rigid than human menisci *(11,29)*. Therefore the use of our local aftertreatment protocol may have contributed to the low amount of horizontal displacement.

Also, the use of a straight sawbone block as a tibia condyle does not represent physiologic conditions. Ligamentary meniscal anchorage was not taken into account while the use of glue as a fixation device might have influenced calculation of construct stiffness because of creating a different mechanical constraint. It is obvious that usage of sound bovine knee joint would have provided more physiologic results.

The study did not answer the biological side of healing. Based on clinical trials, as mentioned above, healing of the lesion can occur. Further weaknesses must be remarked. A worst-case scenario with up to 100.000 cycles – as recently published for vertical lesions *(23)* – is not included. As noted above, technical failure during load to failure testing prevented us from giving an indication which amount of load exceeding our local aftertreatment protocol could be withstood by suture. Also, shear forces could not be measured.

Strengths of our study are the use of matched pairs of medial and lateral menisci and an equal control group, creating a good reference for meniscal behavior in an unsutured condition.

This study compared sutured full and partial horizontal meniscal lesions with corresponding unsutured torn menisci. Horizontal displacement was insignificant in all tested groups. An answer regarding biology of healing is not given with the present study. Questions remain regarding the used model. Further testing in a more physiologic setting is required to scrutinize the reported findings.

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