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Influence of Sutures on Cartilage Integrity: Do Meniscus Sutures Harm Cartilage? An Experimental Animal Study

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Purpose: To evaluate whether different suture materials in meniscal repair may harm cartilage. **Methods:** A preloaded linear friction testing setup including porcine knees with porcine cartilage, porcine meniscus, and different suture materials (braided nonabsorbable, absorbable monofilament) was used. Five groups with different tribological pairs were tested: cartilage on meniscus (control), cartilage on cartilage (control No. 2), and cartilage on different meniscus sutures (3 groups). Cartilage integrity was analyzed macroscopically by the India ink method and histologically using Giemsa-eosin–stained undecalcified methyl methacrylate sections. Cartilage lesions were classified by using a quantitative scoring system. **Results:** The control groups did not show cartilage damage, either macroscopically or histologically. Loading cartilage with sutured menisci led to significant damage of the superficial radial and transitional zones with braided nonabsorbable ($P = .03$) and absorbable monofilament ($P = .02$) sutures at final examination. Menisci sutured with braided nonabsorbable material resulted in deeper damage to the cartilage. However, there were no significant differences between the suture materials. Sutures oriented perpendicular to surface motion led to a larger defect than parallel-oriented sutures. **Conclusions:** Braided nonabsorbable and absorbable monofilament suture materials cause significant damage to cartilage during long-term cyclic loading in vitro. The extent of damage depends on suture orientation. **Clinical Relevance:** This study provides data on the extent to which different suture materials in meniscus repair may harm cartilage.

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One main risk factor for the development of osteoarthritis is loss of meniscal tissue.[1,2] Most studies show improved outcome with meniscus repair over the long term.[3-7]

The methods of meniscal repair have changed from open[4] to arthroscopic techniques[6] and are based on different biomaterials. Current therapies include use of braided nonabsorbable sutures, such as FiberWire (Arthrex, Naples, FL) or Ultrabraid (Smith & Nephew, Andover, MA), with special needles for an inside-out or an all-inside repair (Meniscal Cinch [Arthrex],[8] Fast-Fix [Smith and Nephew][9,10]). These sutures are very stable,[11] and sufficient meniscal repair can even be achieved in complex and older tears. Parallel to the availability of these new materials, a change in paradigm occurred during the past decade. In the past, for the most part, acute lesions in the red-red/red-white zone of the meniscus were repaired because these lesions have an increased healing potential. During that time, absorbable monofilament sutures such as PDS (Ethicon, Somerville, NJ) were often used. Absorbable sutures, however, guaranteed only a stable fixation for the first weeks. Therefore, it was mandatory for a successful meniscal repair that the tissue has sufficient healing potential. With the new strong nonabsorbable devices, the repair might be permanent, even if the meniscus has little or no healing

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capacity. In addition, with new techniques and easy-to-use devices, meniscal repair techniques have become easier, and more surgeons are able to perform meniscal repair. Current studies on meniscus repair, for the most part, analyze the rerupture rate, the clinical results, and sometimes the progression of osteoarthritis, but the development of local cartilage defects has not been analyzed.[9] In addition, data on the effects of permanent materials, such as the previously mentioned braided sutures, on cartilage integrity are limited.[12,13] Therefore, the purpose of this study was to evaluate whether different suture materials used in meniscal repair may harm cartilage. We hypothesized that use of common suture materials in meniscal repair can lead to cartilage damage.

Methods

Specimen and Study Design

Unpaired fresh-frozen adult porcine knees (n = 30; age between 6 and 7 months; body weight 80.5 ± 8.5 kg) were used to perform the study. After slaughter, knees were removed from the animals and stored at −20°C. Each specimen was thawed overnight at room temperature before testing. Knees were carefully cleaned to remove adhering soft tissue. Osteochondral cylinders with a diameter of 10 mm were harvested from the lateral femoral condyle (OATS, Arthrex). The lateral menisci were also explanted. The osteochondral cylinders were inserted into the friction testing machine, and 3 loading cycles per group were performed with either 1 or 6 hours of friction. The explanted menisci were tested natively without any suture by loading with osteochondral cylinders and served as controls (group I). In group II, loading of the osteochondral cylinder was conducted on the tibial plateau without any suture or meniscus. For further testing, the lateral menisci were sutured with different suture materials (group III: 2.0 Ultrabraid; group IV: 2.0 FiberWire; group V: 2.0 PDS) (Table 1). All meniscal probes from groups III to V were equipped with a horizontal and vertical suture in the pars intermedia (parallel and perpendicular to direction of surface motion) (Fig 1). One meniscus from each group was used. The osteochondral cylinders were directly positioned above the sutured meniscus to prevent a complete slide via the suture and thus avoid a "step phenomenon." In 1 of the groups, 3 osteochondral cylinders were used. All cylinders were harvested from uninjured lateral condyles and were carefully checked macroscopically before testing to exclude any cartilage damage. Pre-existing osteoarthritis or softening of the cartilage resulted in abortion of the test. All tests were performed in saline solution (0.9%, room temperature). After the experiment, each osteochondral cylinder was evaluated macroscopically according to the method of Meachim,[14] and results were photographically documented. After the experiment, osteochondral cylinders were fixed and stored in 90% methanol at 4°C and finally embedded in methyl methacrylate.

Linear Friction Testing System

All tests were carried out with the use of a newly designed linear friction testing system. This system consists of a drive mechanism and a fixed base to test 2 friction partners against each other (Fig 2). A second axis for preloading the specimen is attached perpendicular to the linear axis. To apply a linear movement for the specimen, a rotatory motion from an electric motor is translated into a linear move by using a tappet. The linear motion is continuously adjustable from 2 mm up to 20 mm (stroke = 40 mm) with a cycle frequency between 0.5 and 2.25 Hz. To apply a constant preload, a serial setting is used; it consists of a force sensor (maximum load of 200 N, type 8431-5200; Burster Gernsbach/Germany), an adjustable screw, and a spring. The specimen can be fixed to rigid adapter plates by using a screw coupling. A transparent cylindrical dish around the friction partners is used to perform tests in a liquid medium (0.9% saline solution). Test settings can be defined by a control panel for cycle frequency, number of cycles, and applied force (tare function, actual and absolute maximal force [ZX122; Motrona, Rielasingen, Germany]). An emergency switch blocks the drive from execution as long as it is pushed. Stainless steel, aluminum, and polymethylmethacrylate are the only materials used that come in contact with the specimen. For this study, the following parameters were set. The compressive load was 33 N, the sliding amplitude was 5 mm, and the

Table 1. Characteristics of All Study Groups and Statistical Differences

	Loading	1-Hour Friction, n	6- Hour Friction, n	Histologic Cartilage Damage After 1 Hour, Points	Histologic Cartilage Damage, After 6 Hours, Points
Group I (n = 6)	Cartilage/meniscus	3	3	0 ± 0	0 ± 0
Group II (n = 6)	Cartilage/cartilage	3	3	0 ± 0	0 ± 0
Group III (n = 6)	Cartilage/meniscus/Ultrabraid (Smith & Nephew)	3	3	3 ± 0 (*P* = **.046**)	3 ± 0 (*P* = **.03**)
Group IV (n = 6)	Cartilage/meniscus/FiberWire(Arthrex)	3	3	3.3 ± 0.58 (*P* = .059)	3.67 ± 0.58 (*P* = **.03**)
Group V (n = 6)	Cartilage/meniscus/PDS (Ethicon)	3	3	2.3 ± 0.58 (*P* = .11)	3 ± 0 (*P* = **.02**)

NOTE. Points are expressed as mean ± standard deviation. Boldface indicates statistical significance by Wilcoxon/Kruskal-Wallis test ($P < .05$).

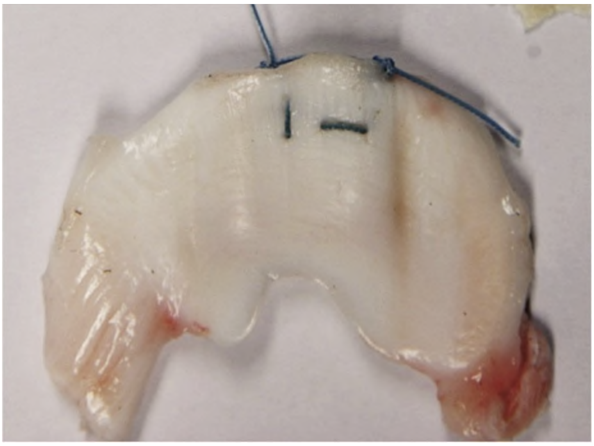

Fig 1. Pig meniscus with a vertical and horizontal suture (length, 5 mm each). The terms "vertical" and "horizontal" indicate the orientation of the suture with respect to the prevailing direction of joint surface motion during knee joint flexion and extension.

cycle frequency was 1 Hz. The load of 33 N was calculated in regard to the pig's weight (average, 80.5 kg), the articular surface of a porcine knee, and the diameter of the osteochondral cylinder (10 mm). The stress rate was therefore 0.42 MPa. An axial load of up to 5 MPa leads to an elastic deformation and no break of cartilage in porcine knees.[15] In comparison, the equilibrium contact modulus in bovine knees is 0.62 ± 0.1 MPa.[16] Therefore, the stress rate used was very low. The cycle frequency was adapted to normal walking pace.

Macroscopic Examination

All osteochondral cylinders were stained by the India ink method[14] for a macroscopic view and first impression of the defect. A macroscopic classification system was not used because the histologic scoring system appeared to be more appropriate for classifying the defect characteristics.

Histologic Examination and Classification

All probes were first dehydrated in ascending alcohol concentrations and then cleared in xylene. After an additional washing step in 100% methanol, specimens were embedded in methyl methacrylate.[17] After polymerization of the methyl methacrylate, the blocks were cut with an annular diamond coated saw (Leica saw microtome SP1600; Leica, Nussloch, Germany). Specimens were oriented in such a way that 100-μm-thick sections perpendicular to the cartilage surface were cut through the central part of each bone-cartilage cylinder. All sections were glued on plastic slides, ground, polished, and stained with Giemsa-eosin. A histologic scoring system was used to assess the depth (as a surrogate marker for severity of cartilage damage) of a

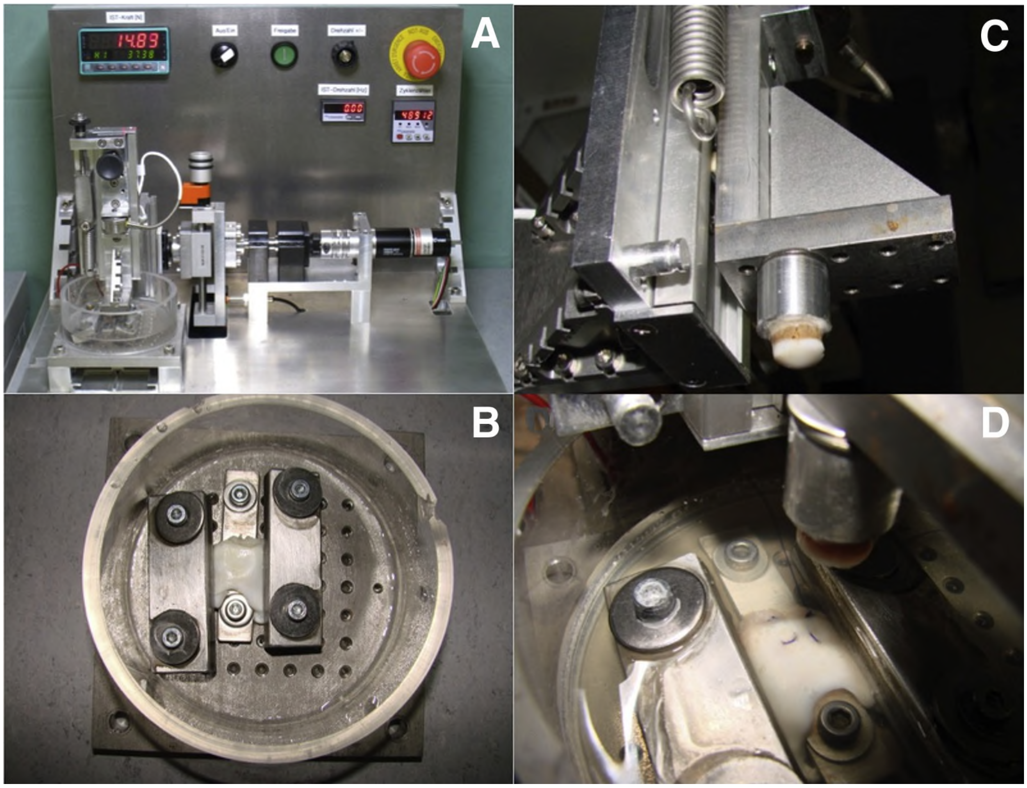

Fig 2. Preloaded linear friction testing system. (A) Complete machine with all controllers. (B) Distal platform for cartilage/meniscus/suture and medium, fixed bearing. (C) Proximal friction part, mobile bearing. (D) Proximal (cartilage) and distal friction parts (meniscus and sutures).

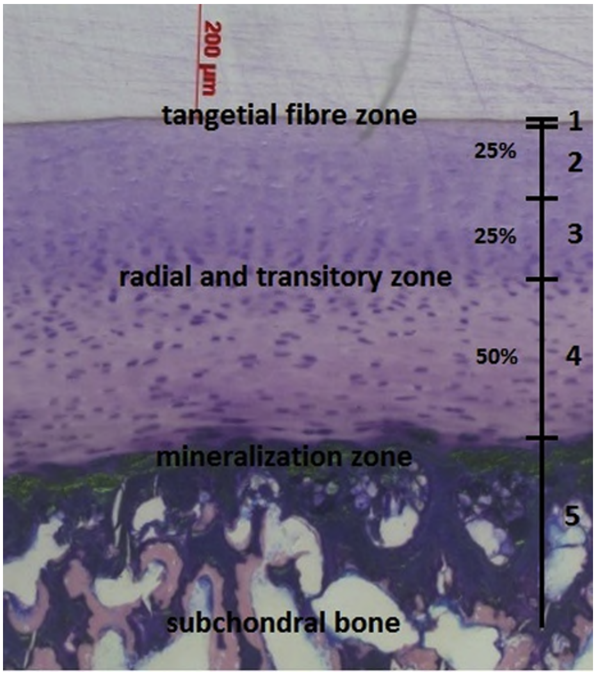

Fig 3. Scoring system for damage classification. The scoring system represents a cross-section of cartilage and bone structure. Values from 0 to 5 were assigned to damage of the following layers: 0 = no damage detectable; 1 = damage of the tangential (i.e., superficial) zone of cartilage; 2 = damage of the tangential zone and up to 25% of the transitional and radial (i.e., deep) zone of cartilage; 3 = damage of the tangential zone and up to 50% of the transitional and radial (i.e., deep) zone of cartilage; 4 = damage of the tangential zone and up to 100% of the transitional and radial (i.e., deep) zone of cartilage; 5 = damage of all nonmineralized layers plus the underlying mineralized cartilage layer.

potential defect (Fig 3). Depending on the number of cartilage layers affected by the defect, a defect severity score was assigned to each specimen. Assessment was based on bright field microscopy and supported by polarized light imaging for better discrimination of cartilage layers. A.V. and S.M. were blinded to treatment of individual specimens and scored representative sections independently. Because the histologic appearance of sections from the various groups was very uniform, the scoring process was easy to perform. For histologic classification, only the horizontal sutures were analyzed because the classification system is focused on depth of damage rather than width.

Score value were as follows: 0 = no damage detectable; 1 = damage in the tangential (i.e., superficial) zone of cartilage; 2 = damage in the tangential zone and up to 25% of the transitional and radial (i.e., deep) zone of cartilage; 3 = damage in the tangential zone and up to 50% of the transitional and radial (i.e., deep) zone of cartilage; 4 = damage in the tangential zone and up to 100% of the transitional and radial (i.e., deep) zone of cartilage; 5 = damage in all nonmineralized layers plus the underlying mineralized cartilage layer.

Statistical Analysis

Histologic cartilage damage was compared between the different groups. A nonparametric Wilcoxon/Kruskal-Wallis test for multiple comparisons and ordinal data was used to prove statistical significance. A level of significance of $\alpha = 0.05$ was selected.

Results

Macroscopic Results

Osteochondral cylinders from groups I and II did not show any cartilage defect after 1 and 6 hours of loading after they were stained with Indian ink. Osteochondral cylinders from groups III, IV, and V showed clear evidence of cartilage defects after 1 and 6 hours of loading (Fig 4). Differentiation among depths of different cartilage damage was not possible with this method. In all suture groups, horizontal sutures led to larger cartilage defects than vertical ones (Fig 4).

Histologic Results

Cartilage thickness was comparable in all specimens, and cartilage damage could be assessed with the scoring system described previously. Loading cartilage with sutured menisci led to significant damage in the superficial radial and transitional zones in groups III, IV, and V (braided nonabsorbable, $P = .03$; absorbable monofilament, $P = .02$) after 6 hours of cyclic loading. After 1 hour of cyclic loading, only group III showed significant cartilage damage ($P = .046$) (Table 1). Menisci sutured with braided nonabsorbable material showed deeper damage in the cartilage. However, there were no significant differences between the suture materials.

In groups I and II, no cartilage damage was detected after loading of 1 and 6 hours (0 ± 0 points, median 0), and therefore, cartilage integrity remained unaffected.

In group III (braided nonabsorbable, Ultrabraid), all probes that were loaded for 1 hour revealed cartilage damage of up to 50% in the radial and transitional zones (3 ± 0 points; median 3; $P = .046$), which did not become more severe after 6 hours of loading (3 ± 0 points; median 3; $P = .03$).

Specimens from group IV (braided nonabsorbable, FiberWire) loaded for 1 hour showed cartilage damage of up to 75% in the radial and transitory zones (3.3 ± 0.58 points; median 3; $P = .059$). Specimens loaded for 6 hours showed damage of up to 100% in the radial and transitory zones (3.67 ± 0.58 points; median 4; $P = .03$).

Probes of group V (absorbable monofilament, PDS) loaded for 1 hour revealed cartilage damage of up to 25% in the radial and transitory zones (2.3 ± 0.58

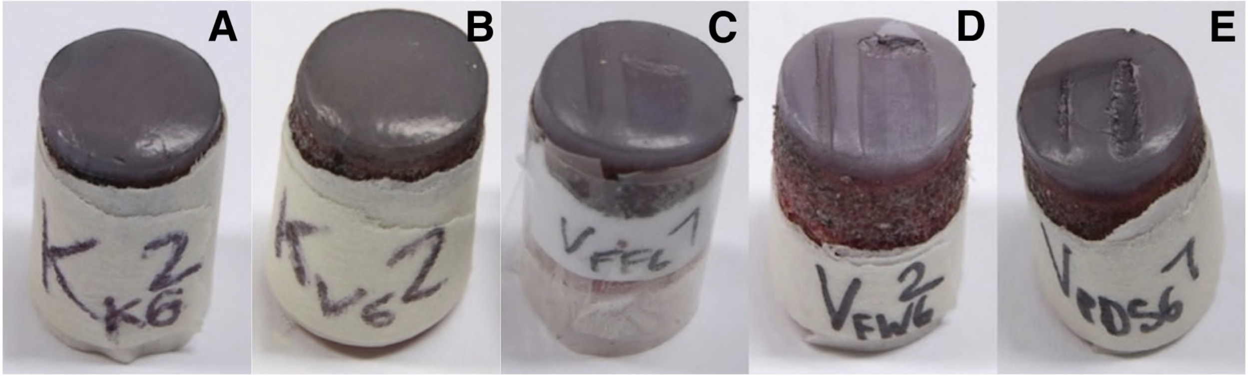

Fig 4. Macroscopic appearance of cartilage surfaces after India ink staining. (A) Control group, cartilage/meniscus 6 hours. (B) Meniscectomy group, cartilage/cartilage 6 hours. (C) Nonabsorbable suture—cartilage/Ultrabraid 6 hours, horizontal (left) and vertical sutures (right). (D) Nonabsorbable suture—cartilage/FiberWire 6 hours, horizontal (left) and vertical sutures (right). (E) Absorbable suture—cartilage/PDS (Ethicon) 6 hours, horizontal (left) and vertical sutures (right).

points; median 2; $P = .11$). Loading of 6 hours showed damage of up to 50% in the radial and transitory zones (3 ± 0 points; median 3; $P = .02$). In all specimens treated with sutures, the superficial zone of cartilage was affected by a lesion that could have a negative effect on cartilage integrity (Fig 5). Depth of damage to the cartilage was comparable in vertical and horizontal defects. However, because of increased damage, volume lesions caused by vertical sutures (pars intermedia = perpendicular to surface motion) indicated a more severe type of lesion (Fig 6).

Discussion

In the present study, braided nonabsorbable and absorbable monofilament suture materials induced cartilage lesions in the upper cartilage part. The lesions caused by braided nonabsorbable sutures were more severe. Moreover, it was clearly demonstrated that sutures oriented perpendicular to surface motion lead to larger defects than parallel-oriented sutures.

Meniscus lesions are frequent and caused by trauma or degeneration.[3,4] Functional loss of meniscal tissue caused by rupture or meniscectomy can lead to

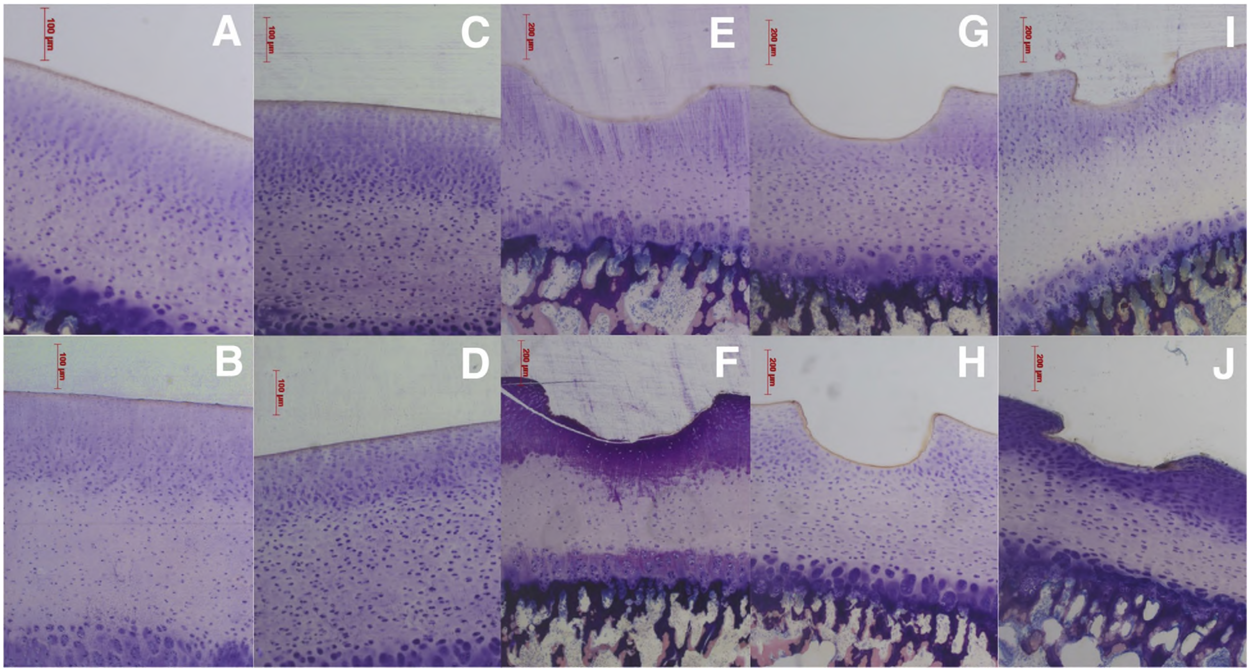

Fig 5. Histology of methyl methacrylate—embedded specimens, Giemsa-eosin—stained sections. (A) Control group 1 hour. (B) Control group 6 hours. (C) Meniscectomy group 1 hour. (D) Meniscectomy group 6 hour. (E) Ultrabraid (Smith & Nephew) group 1 hour. (F) Ultrabraid group 6 hours. (G) FiberWire group 1 hour. (H) FiberWire (Arthrex) group 6 hours. (I) PDS (Ethicon) group 1 hour. (J) PDS group 6 hours.

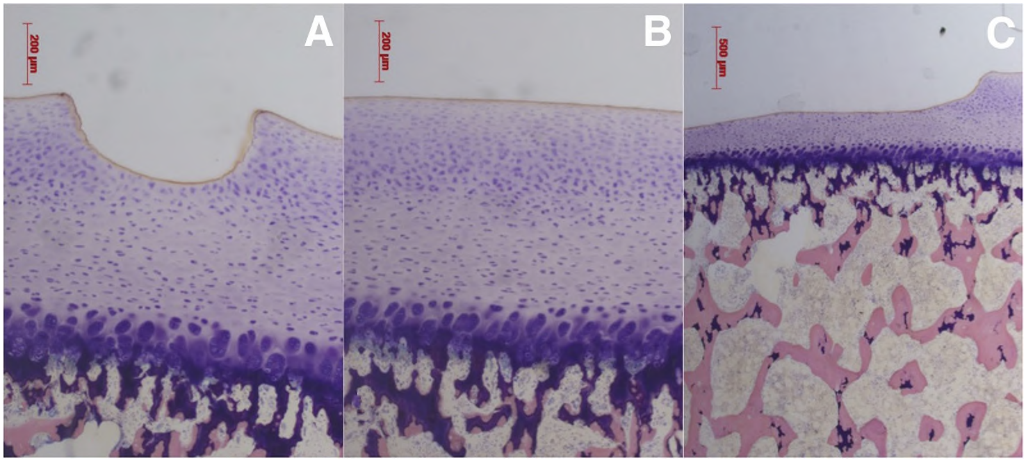

Fig 6. Histology of methyl methacrylate—embedded specimens, Giemsa-eosin—stained sections. Note the difference in damage patterns between vertical and horizontal sutures. (A) FiberWire (Arthrex) 6-hour horizontal suture with low-volume cartilage defect. (B) Cartilage between sutures without defect. (C) FiberWire 6-hour vertical suture with high-volume cartilage defect.

cartilage damage or even osteoarthritis.[2,5,7] Therefore, suturing of the meniscus is of great importance and represents a key procedure in orthopaedic surgery. Considering the results of present study, sutures oriented parallel to joint motion should be used, if possible, when a ruptured meniscus is sutured. Practically, this means vertical sutures should be used in the anterior and posterior parts, and horizontal sutures should be used in the middle part of the meniscus. However, this concept is often limited by the rupture pattern, as in buckle-handle tears in which vertical sutures are preferred because of their superior biomechanical stability.

Rolauffs et al.[18] showed that the disruption of and a lesion in the superficial cartilage zone result in immediate loss of biomechanical function. It thus is a perturbing fact that in our study the superficial layer was damaged in all suture groups. In combination with delayed superficial proteoglycan and glycosaminoglycan loss, these changes may predispose the articular surface to further softening and tissue damage, thus increasing the risk for development of secondary osteoarthritis.[18,19] Our results are based on an in vitro study and therefore cannot be applied to an in vivo trial. However, these results indicate that suture material may harm superficial cartilage layers, and use should be minimized. The cartilage pressure used in our experiments (0.42 MPa) is at a very low level in regard to healthy weight bearing in animals[15,16] and humans during walking and simulates load associated with standing in a pig. Therefore, an experimental overload in the system we used is unlikely.

It has been shown in many studies that meniscectomy will lead to osteoarthritis[1,20] by causing decreased joint congruency and a focal increase in cartilage load bearing. Therefore, the aim of meniscus repair is restoration of normal load distribution throughout the knee joint surfaces. Controversy exists in studies about the benefit of meniscal repair in protection against osteoarthritis development in comparison with (partial) meniscectomy.[2,4,5,21] In the study by Rockborn et al.,[21] in which nonabsorbable sutures were used, the rate of osteoarthritis did not differ between patients who had meniscus repair and those who had meniscectomy. The use of nonabsorbable sutures could be 1 explanation for these results. In contrast, in the study by Stein et al.,[6] in which absorbable monofilament sutures were used, a lower osteoarthritis rate in knees with a repaired meniscus in contrast to knees treated with meniscectomy, was described. However, the study has some methodical problems, such as different pathologies in the 2 groups, and the pertinence of conclusions is therefore limited. However, this is a problem of almost all current clinical meniscal studies.

Long-term results regarding the new suture generation (braided nonabsorbable polyethylene materials) are not available because these sutures have only been available for the last few years. These sutures have an advantage for meniscus repair. Even in cases of a chronic meniscal tear, with these sutures, it is possible to achieve a stable meniscal repair as compared with use of absorbable monofilament sutures. Therefore, the number of indications for meniscal repair has increased during recent years. However, it is still not known whether these procedures will lead to a real clinical benefit in the long term. In contrast, our results clearly show that these sutures can lead to more cartilage damage caused by abrasion than monofilament sutures. The second advantage of absorbable sutures is their disintegration over time. Therefore, avoidance of weight bearing for a certain postoperative period can protect the cartilage when absorbable sutures are used. In cases in which nonabsorbable sutures are used, this effect is less likely to occur. The question of whether absorbable sutures would be less harmful cannot be answered within this study.

Although it remains unclear to what extent our in vitro results can be applied to the clinical situation, they should be taken as a warning. Accelerated rehabilitation programs in which immediate joint loading is allowed after a meniscal repair[22] might increase the risk of immediate abrasive cartilage damage and therefore should be considered carefully before they are prescribed. The extent to which tissue overgrowth will subsequently occur cannot be predicted today, but it could serve as a protective mechanism, especially in cases in which braided nonabsorbable sutures were used.

Limitations

This study presents in vitro data obtained with joint kinematics different from kinematics associated with normal human knee movement. However, the cartilage loading was adapted in this knee simulator to match that of a normal porcine knee. Moreover, the scoring system we used is new and not previously validated; thus, the results cannot be compared with previous results. The main limitation of our study is the fact that we performed a meniscus repair when no meniscus tear was present (Fig 1). Because of the absence of a meniscus tear, our study mainly allows for testing of a material's properties (and its orientation). Moreover, our sample size of 3 per group is very small, and therefore statistical analysis is of limited value.

However, the cartilage damage was extremely reproducible, and loading of cartilage and meniscal tissue without a suture did not lead in a single case to any kind of cartilage defect. It is possible that in vivo, the sutures will be covered by tissue overgrowth and therefore cartilage will be better protected than in our experimental setup, which resembles the initial phase of healing immediately after meniscus repair. This assumption must be tested in vivo by using an animal model appropriate for meniscal repair studies.

Conclusions

Braided nonabsorbable and absorbable monofilament suture materials cause significant damage to cartilage during long-term cyclic loading in vitro. The extent of the damage depends on suture orientation.

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