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Medial meniscus replacement by a fat pad autograft

An experimental study in sheep

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Summary. *The medial meniscus in 15 sheep was replaced by a pediculated infrapatellar fat pad graft and resulted in the development of a macroscopically meniscus-like structure within 6 months. Five additional sheep with a meniscectomy were controls. Degenerative changes in the fat pad autograft were visible after one year. Osteoarthritis of the weightbearing medial compartment was detected after 6 months. A temporary protective effect on the cartilage could be attributed to the autograft, but the long term results indicated that this was not permanent. Fat is not suitable as a meniscal substitute.*

Résumé. *Le remplacement du ménisque interne par le paquet graisseux sous-rotulien pédiculé chez 15 moutons (3 groupes de 5 étudiés à 3, 6 et 12 mois) montre le développement d'une structure pseudo-méniscale dans les 6 mois. 5 autres moutons après ménisquectomie ont été étudiés comme groupe de contrôle. Les lésions dégénératives du paquet graisseux transposé, étaient visibles 1 an après l'insertion. Une arthrose du compartiment interne fut détectée 6 mois après la transplantation. On peut attribuer un effet chondro-protecteur temporaire au paquet graisseux transposé, cependant, les résultats à long terme chez l'animal du remplacement méniscal par du tissu graisseux ne peut être considéré comme une solution définitive. Le remplacement méniscal par autogreffe à partir de tissu conjonctif comme un tendon est peut-être une méthode envisageable, mais le tissue graisseux n'est pas un bon substitut méniscal.*

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Introduction

Total meniscectomy changes load transmission in the knee [1, 27, 28, 37, 42, 46], the contact area is reduced and contact stress in the involved compartment increased [5]. Early degenerative arthritis follows [9, 13, 19, 22, 33, 45] as well as increasing instability [8, 16, 29, 32, 40]. A regenerated meniscus offers little mechanical benefit [44].

The posterior horn of the medial meniscus acts as a synergist to the anterior cruciate ligament (ACL) [38]. Anteroposterior instability after ACL tears is worse if there is no meniscus [6, 17, 29], and its absence may jeopardise reconstruction or replacement of the ligament [56].

The importance of the meniscus necessitates conservative resection [10, 19], reconstruction [10, 48, 58] or replacement [18, 20, 26, 51, 54]. Three possibilities for replacement are (a) an allograft [18, 20, 54, 58], (b) a meniscal prosthesis [47, 49, 51, 53], and (c) an autograft [25, 26].

Allografts were successful initially in animal experiments [21, 36, 52, 54, 55, 58], but the clinical results are not convincing [18, 24, 34]. Fresh grafts may transmit disease and may deteriorate when sterilised [2, 7, 18, 20, 57, 59]. Arthroscopy has shown that the grafts decrease in size [24] and the immune system may not accept a fresh

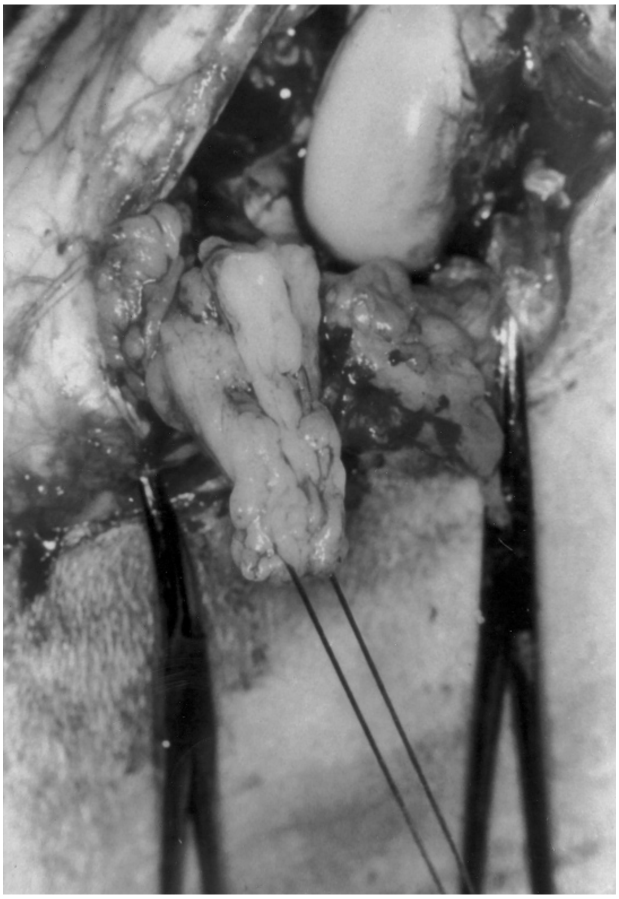

Fig. 1. The medial half of the infrapatellar fat pad. Its tip is tagged with nonabsorbable thread used for fixation

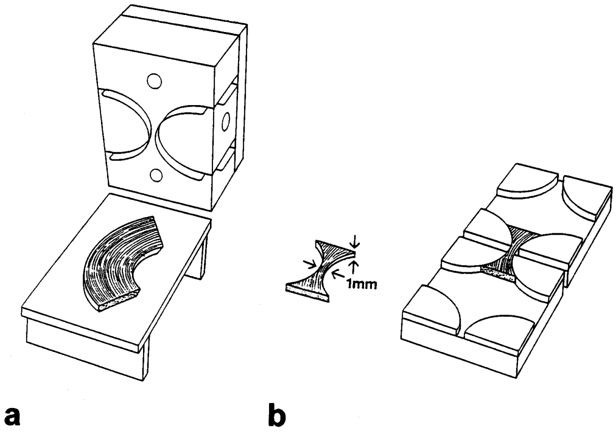

Fig. 2 a, b. Diagram showing the specimen for tensile testing. The square area is 1 mm² at its narrowest part. **a** 1 mm thick slice made by deep-freeze cutting. **b** Dumb-bell shaped specimen stamped out with razor blades

meniscal allograft [14, 50, 54, 60]. There are no materials suitable for use, and early meniscal prostheses were failures [53].

Consequently the idea of autografts arose and tendons [25, 26] and fatty tissue [15, 30] have been used. Pediculated grafts of the infrapatellar fat pad changed to meniscus-like tissue when inserted between the joint surfaces [39]. Replacement with fatty tissue has been attempted, but the first clinical results were disappointing [34]. We therefore designed an animal experiment to evaluate the procedure and on the advice of others [12, 18, 41], chose sheep as the experimental model.

Materials and methods

Twenty skeletally mature female, but not pregnant, Merino sheep were operated on, after Institutional Review Board Approval was obtained. Initially all animals were marked with an ear-stud and then allocated into 4 groups of 5 animals each.

Resection of part of the Achilles tendon was performed on the right hindleg to ensure temporary nonweightbearing. The approach to the knee was an extended medial parapatellar incision with femoral detachment of the medial collateral ligament. In every animal a medial meniscectomy was carried out and the medial half of the infrapatellar fat pad removed. In group 1 (controls) nothing more was done. In groups 2, 3 and 4 the medial meniscus was replaced with a halved pedunculated fat pad. The pad was divided longitudinally, the tip of the medial half was mobilised and tagged with a nonabsorbable thread (2/0 USP) (Fig. 1). Both ends of the thread were fed through parallel drill-holes in the tibia from the posterior intercondylar area to the medial surface of the anterior tibial plateau. The fatty tissue was sutured to the capsule with 4 absorbable threads creating a semicircle. The medial collateral ligament was then repaired and the wound closed. Every animal was given pre- and postoperative antibiotics. All the operations were done by the same surgeon (DK).

After 3 months (group 2), 6 months (group 3) and 12 months (group 4), the animals were sacrificed and the right hindleg disarticulated at the hip. Angiography was carried out on one animal in each group. Immediately after opening the joints, photographs were taken in situ and again after removal of the graft.

For tensile tests, 1 mm thick slices were obtained by cryostat sectioning of the posterior half of the fat menisci (Fig. 2 a). From these sections, dumb-bell shaped specimens were removed with a purpose-designed device (Fig. 2 b) along the visible lines of the fibres. The specimens were fixed between special grips, mounted on the material testing machine and tested to failure.

The menisci and autograft for light and electron microscopy were immersion-fixed en bloc in 3% glutaraldehyde, buffered with 0.1 M sodium cacodylate HCl. Samples obtained from the tissue close to the medial collateral ligament were used. For light microscopy, the samples were embedded in Epon^R or paraffin, then cut into 1 µm thick sections and stained with an alkalinised Toluidine Blue solution, Haematoxylen-eosin or Van Giesson. The larger posterior part of the specimen was used for scanning electron microscopy [26].

Results

All the wounds healed satisfactorily. In the first 4 weeks after operation, the sheep avoided

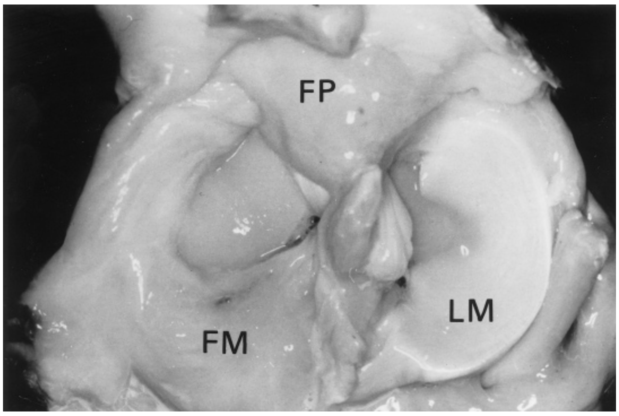

Fig. 3. Complete fat meniscus (*FM*) 12 months after grafting. Normal lateral meniscus (*LM*). Remainder of the infrapatellar fat pad (*FP*)

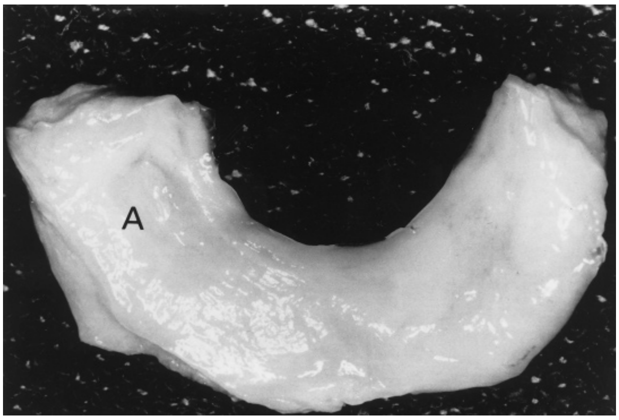

Fig. 4. Isolated specimen of a fat meniscus (*A* = anterior)

weightbearing on their affected leg. After 12 weeks, only 3 showed slight lameness and after 24 weeks none were lame. After sacrifice and disarticulation no medial instability was detected.

Macroscopic findings

After total meniscectomy and autograft fat pad replacement, meniscal regeneration was found in every knee, but was never more than 25% of the width and 50% of the height of a normal meniscus. At 3 months (group 2) one specimen had a complete fat meniscus which was the normal shape and size of a sheep's meniscus, although it was softer. Figures 3 and 4 show a complete fat meniscus in situ and after removal from the joint. Incomplete fat menisci about three-quarters the size of normal were found in 4 cases (group 2). Similar results were found at 6 months (group 3). At 12 months (group 4), one animal had a regenerated meniscus

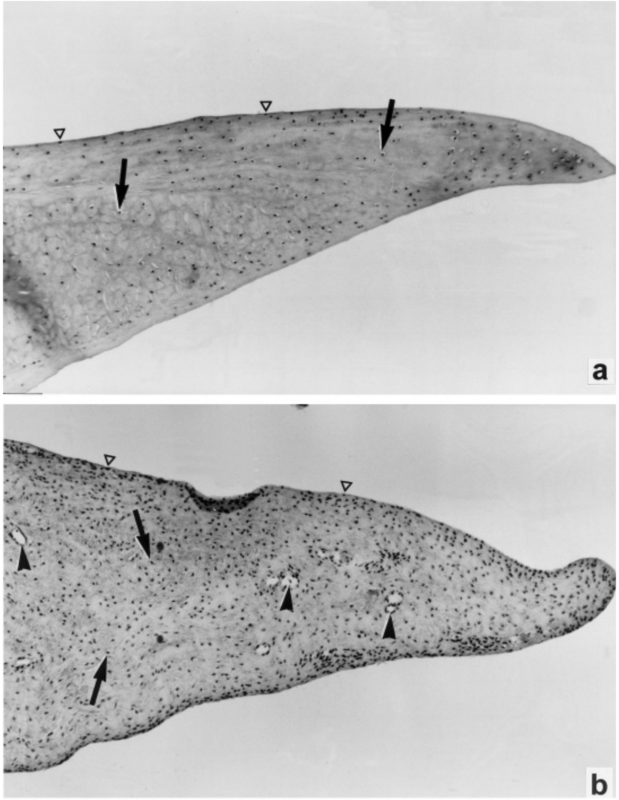

Fig. 5. Free edge of a normal meniscus and (**b**) of a fat meniscus. Chondrocyte-like cells (*arrows*), synovial cells (*triangles*). (Van Giesson stain, ×40)

similar to those in the controls; in 4 there was an incomplete fat meniscus. No animal in group 4 had a complete intact fat meniscus.

Initially there were no articular cartilage defects in the medial tibiofemoral compartment. After 12 months, every animal in group 1 had fibrillation and discoloration of the medial tibial plateau with softening and discoloration of the cartilage on the medial femoral condyle. After meniscal replacement, intact hyaline cartilage was present macroscopically in the 5 animals in group 2. After 6 months (group 3), 2 knees had chondromalacia of the tibial plateau. After 12 months (group 4), all but one medial compartment showed tibial cartilage defects.

Histology

The surface of the articular cartilage of the medial tibial plateau, the surface of the fat menisci, and their internal structure, was examined. Major surface damage with deep defects was evident in the centre of the joint surface after meniscectomy (group 1), but lesions of this size were not seen

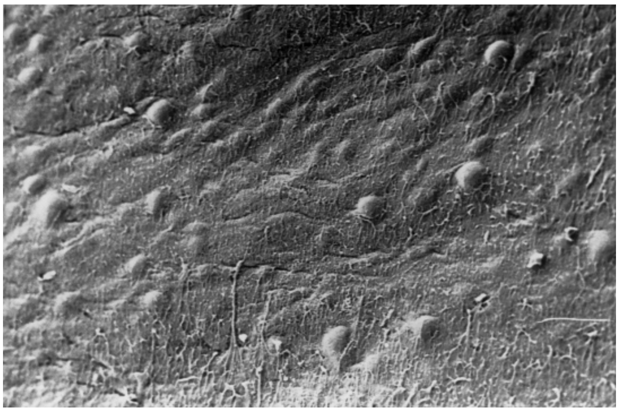

Fig. 6. SEM (×380) showing the surface of a fat meniscus. The bulging areas are produced by nuclei of fibrochondrocytes

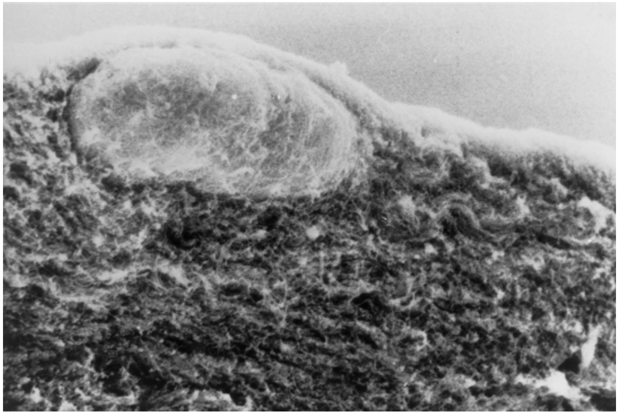

Fig. 7. SEM (×3300). The nucleus of a fibrochondrocyte bulging the surface of a fat meniscus

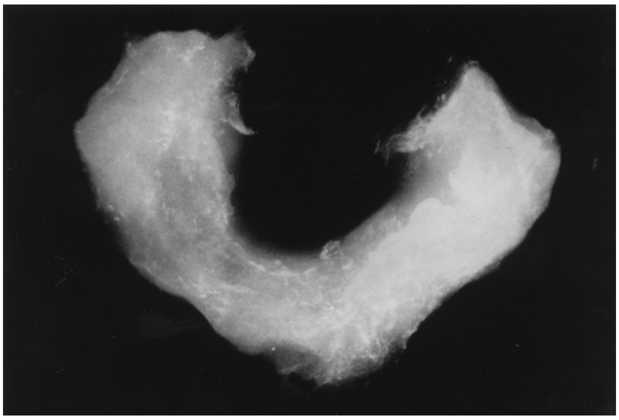

Fig. 8. Microangiograph of a fat meniscus at 12 months showing vascularisation throughout its substance

after meniscal replacement. A completely intact cartilage surface was, however, only found in one specimen after 3 months. All the other joints showed surface damage in spite of meniscal replacement. After 3 months, fat cells could only be found near the capsule. Most of the autograft had become fibrous connective tissue (Fig. 5), but in the centre chondrocyte-like cells were identified and there were areas of mucoid degeneration. The whole fat meniscus appeared highly vascularised and was covered by a thick layer of synovial tissue. Occasional histiocytes containing haemosiderin were identified. The same was seen at 6 months (group 3), but there were no foreign body giant cells or histiocytes. After 12 months (group 4), degenerative changes were discernable in the fat meniscus with clusters of chondrocyte-like cells and further areas of necrosis, but no fat cells were present. The synovial covering was limited to the periphery. Minor surface tears were in the process of repair and the arrangement of collagen was irregular.

Scanning electron microscopy

The surface of the fat meniscus showed characteristic bulges which represented cells immediately adjacent to the surface with prominent nuclei of fibrochondrocytes (Fig. 6, 7). These bulges are also present in normal menisci. The internal structure of the fat menisci consisted of collagen fibre bundles arranged at random interspersed with lines of chondrocyte-like cells.

Microangiography

Complete vascularisation of the fat pad persisted after 12 months (Fig. 8). The vessel system was equally distributed over the grafted meniscus and was not limited to the synovial layer.

Biochemanics

Material from the infrapatellar fat pad was too soft for tensile testing by our system. Specimens from the fat menisci yielded reproducible results (Table 1) with no statistical difference of failure stress and the tensile modulus over varying periods of time. In contrast, there was a highly significant difference between the mechanical properties of the fat meniscus and that of a normal sheep's meniscus (t-test, $p < 0.01$). The failure stress and tensile modulus of the fat meniscus were only 10% to 20% of the normal meniscus.

Table 1. Mechanical properties of meniscus and fat meniscus. Mean values and standard deviations

	Failure stress (N/mm²)	Tensile modulus (N/mm)
Normal meniscus	23 ± 5.1	22 ± 4.2
Fat meniscus (3 month)	4.0 ± 3.8	3.5 ± 2.7
Fat meniscus (6 month)	3.7 ± 2.9	3.1 ± 0.8
Fat meniscus (6 month)	2.1 ± 1.5	1.7 ± 1.0

Discussion

The possibility that tendon, when used as a ligament replacement, might change into a functionally adequate structure has been recognised [23, 31, 43], and tendon from the extensor apparatus of the knee will change to a meniscus-like structure when used as a meniscus substitute [25, 26]. Removing tissue from this site has some morbidity [11], but this could be diminished by using another local tissue which is also capable of transformation under load and tension. Degenerative joint surfaces have been covered with autogenous fatty tissue and successful results reported [15, 30, 39]. Preliminary results in a small number of patients have suggested that methods designed for the elderly arthritic joint could not be transferred to meniscal replacement in young, active individuals [34].

Our results have shown that fatty tissue could be transformed into fibrous connective tissue within 6 months. Histology showed remnants of the original tissue only in the 3 month specimens (group 2). Necrosis occurring after 12 months represents a secondary process and is an early indication of disintegration of the replacement tissue. The short life of a meniscus substitute is confirmed by biomechanical testing, and these findings are critical in the evaluation of any meniscal replacement [18, 47, 49]. The tensile properties of fat menisci were disappointing compared with normal menisci. The ultimate tensile strength was significantly lower and was less than 20% of normal. There was a tendency for reduction of tensile strength with time, but this was not statistically significant. Deterioration over time was not seen in tendon meniscus studies [25, 26]. We did not attempt compression testing, as has been recommended [37], because this would disrupt the fibrous architecture of the meniscus and make the results difficult to interpret. In tensile testing, the tension was created along the peripheral circumferential fibres which closely simulate normal function [25, 37].

Microangiography and histology showed rich vascularisation throughout the fat meniscus which distinguished it from normal where vascularisation is limited to its peripheral third and the adjacent capsule [3]. A central vessel-free zone did not develop in our models; this phenomenon occurs in hyalinised menisci in contrast to frozen or cryopreserved meniscal grafts [4, 35].

Our findings on the condition of the joint are supported by others [1, 46], and invite conclusions concerning the mechanical effectiveness of the meniscal replacement. Macro- and microscopic comparison of the medial and lateral plateaux indicate that a temporary protective effect on the joint cartilage could be attributed to the fat meniscus. In contrast, the results of tensile tests and histological indications of early degeneration within the fat meniscus, cast serious doubt about a permanent protective effect comparable to the normal meniscus. Our study confirms the enormous functional adaptability of connective tissue [23, 27, 30, 31, 43]. The implantation of pediculated infrapatellar fat pad autografts in sheep showed that the graft was transformed into what looked like a meniscal structure. Such tissue should be evaluated by biomechanical tests since the morphological picture may lead to erroneous conclusions. Temporary protection of joint cartilage can be attributed to the replacement meniscus, but our results in sheep suggest that the infrapatellar fat pad is not an adequate substitute for a damaged medial meniscus in young active persons. Further clinical use of this procedure must be abandoned. If the meniscus is to be replaced by an autograft, tendon from the extensor apparatus seems much more promising [25, 26].

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