Free synovium promotes meniscal healing

Synovium, muscle and synthetic mesh compared in dogs

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We studied the effect of free synovium on the healing of tears in the avascular portion of the menisci in dogs. A longitudinal incision was made in the medial meniscus. In 35 dogs, a free graft of synovium was inserted into the tear and sutured. In 10 dogs, a free graft of quadriceps muscle was used. In 10 dogs, a Dacron mesh was inserted. In the contralateral knee, the tear was sutured without implantation as a control. 2, 4, 6, 8, and 12 weeks after the operation, the menisci were dissected. 11 of the 35 with free synovium were healed. The menisci with muscle grafts, those with Dacron mesh and those in the control group did not heal. Histology showed that tears were repaired with fibrous tissue. Microangiography showed that capillaries grew from the periphery, but they did not reach the tear.

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Only the peripheral 20–30% of the meniscus has a blood supply (Arnoczky and Warren 1982). The earliest experience of meniscal repair in the avascular region was reported by King (1936) showing, in dogs, that a tear can be healed by connective tissue if the tear communicates laterally with the synovial membrane. Veth et al. (1983) described the repair of T-shaped wounds in the menisci of rabbits by implanting synovium. Arnoczky and Warren (1983) observed that longitudinal incisions in the avascular portion of the meniscus in the dog failed to heal; however, the lesion healed with a fibrovascular scar when it was connected to the peripheral synovial tissues at their mid-portion by a vascular access channel. Ghadially et al. (1986) and Kobuna et al. (1995) reported healing of longitudinal cuts in the avascular region after suturing a flap of synovium into the wound in sheep and dogs, respectively.

Heatley (1980) concluded that meniscus healing depended not on the presence of a vascular supply but rather on the type of cell invading the damaged area. The synovial membrane is well vascularized and contains cells with various biological potentials. Therefore, we investigated the effect of a free synovial flap on the repair of tears in the avascular portion of dog menisci.

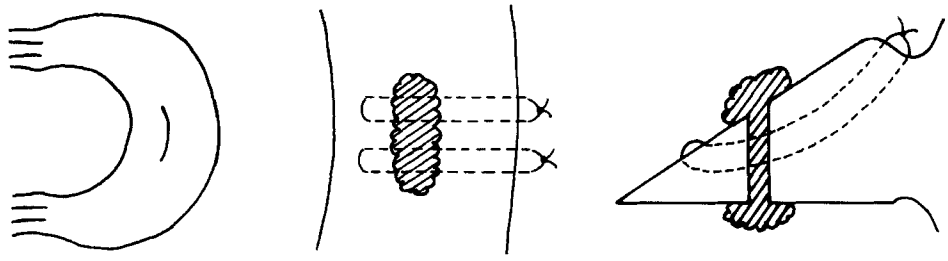
Animals and methods

55 mature mongrel dogs, with a median weight of 20 (12–30) kg, were used. They had free access to water and standard pellet food and were maintained in accordance with guidelines described in the Gunma University "Guide for the Care and Use of Laboratory Animals". Each dog was given ketamine hydrochloride intramuscularly prior to surgery, 25 mg/kg body weight, and was anesthetized with intravenous pentobarbital sodium, 13 mg/kg. Medial parapatellar incisions were made, exposing the medial meniscus of both knees. The meniscus was pulled forwards and a 5–6 mm longitudinal, full-thickness incision was made in the middle of the meniscus, which is avascular (Kobuna et al. 1995).

In 35 dogs, a free graft of the synovium from the same joint was inserted into the tear and sutured by 5–0 nylon (Figure 1). In another group of 10 dogs, a free graft of the quadriceps muscle from the same limb was used. In the remaining 10 dogs, Dacron mesh was inserted. In the contralateral knee, a small piece of synovium was excised, and the tear was sutured without any graft as a control. The capsule and skin were sutured and the limbs were not immobilized. After recovery from anesthesia, the dogs were allowed normal activity in the cages.

2, 4, 6, 8, and 12 weeks after the operation, the dogs were killed, using pentobarbital sodium (Table 1). The medial meniscus was dissected from each knee and examined by gross inspection, microangiography and histologically (Kobuna et al. 1995). The meniscus was judged to be healed when the incision did not open on palpation. 3 transverse sections were taken from each meniscus, and stained with hematoxylin and eosin. For microangiographic evaluation, with an

Figure 1. The procedure for grafting a free synovium into an incision in the medial meniscus.



The longitudinal meniscal incision. A free synovium is stitched into the incision. ▨ free synovium.

Table 1. The number of dogs according to treatment

	Weeks elapsed after operation				
	2	4	6	8	12
Treatment					
Synovium	5	8	8	8	6
Quadriceps muscle	2	2	2	2	2
Dacron mesh	2	2	2	2	2
Controls	9	12	12	12	10

injection technique via the cannulated femoral artery, the vessels of the lower limb were filled with barium sulfate. Transverse or horizontal, 1-mm thick slices of the meniscus crossing the suture site were made, and contact microradiographs were obtained by using a soft x-ray machine (Softex, Japan).

The chi-square test with Yates' correction was used to analyze the differences in the healing rates between the menisci with a synovial graft and the controls. $P < 0.05$ was considered significant.

Results

Macroscopy

Tears of the 35 menisci with synovial free grafts had healed in varying degrees; 14 lesions showed no signs of healing, 21 were covered by a semi-translucent tissue. 10 of these 21 tears opened after the sutures had been removed, the other 11 were healed macroscopically. These 11 consisted of 3 of 8 tears at 6 weeks, 4 of 8 at 8 weeks, and 4 of 6 at 12 weeks. Tears with a free muscle graft, with a Dacron mesh and of the controls were not repaired at any time. The healing rate was significantly greater in menisci with a free synovial graft than in controls at 8 ($p = 0.03$) and 12 ($p = 0.02$) weeks. In most of the healed cases, the tear was not completely repaired at the tibial side. There was no degenerative change in the articular cartilage of the knee with healed and unhealed menisci.

At 2 weeks, the synovial graft was seen in the incision. At 4 and 6 weeks, the graft was covered by a semi-translucent tissue, and the peripheral synovium was elevated, had grown towards the suture site but not reached it. At 8 weeks, the elevation of the synovium had decreased. The implanted muscle tissue and Dacron mesh were not seen after the 4th week.

Histology

Histological examination of the meniscus with a synovial graft at 2 weeks revealed fibrin attached to granulation tissue at the cut end of the menisci which had been opened after the sutures were removed. At 4 weeks, the tear on the femoral side was bridged by immature fibrous tissue, unlike the typical structure of the synovium. Capillaries were not seen at the suture site. At 6 weeks, the tear on the femoral side was repaired by granulation tissue and mature fibrous tissue which had penetrated partially into the meniscus tissue. The tears on the tibial side were not well repaired. At 12 weeks, the bridging fibrous tissue on the femoral side showed more maturation than at 6 weeks, whereas the defect in the fibrous tissue on the tibial side still remained (Figure 2). No fibrin clots or

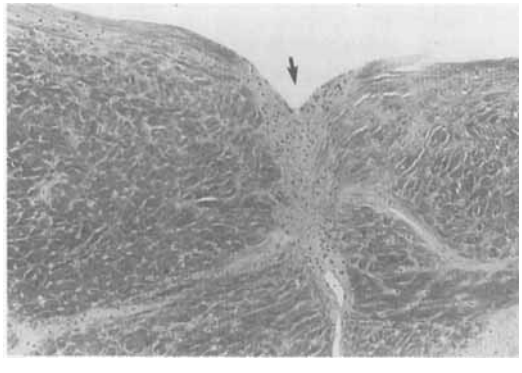


Figure 2. Photomicrograph, of a section of the meniscus, using a free synovial graft at 12 weeks. The tear on the femoral side is repaired by fibrous tissue (arrow). HE, ×63.

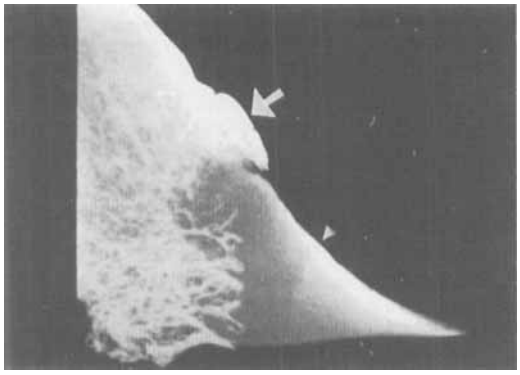


Figure 3. Microangiogram of a section of the meniscus, using a free synovial graft at 8 weeks. The capillary plexus from the parameniscal area (big arrow) does not reach the tear (arrow head).

implanted materials were seen at the cut end of the menisci with a free muscle graft, with a Dacron mesh and of the controls.

Microangiography

Microangiography on the horizontal section at 2 weeks showed that capillaries grew from the periphery of the meniscus towards the tear. However, they did not reach the tear. At 6, 8, and 12 weeks, the capillary plexus had still not reached the tear. The transverse section, made at right angles to the longitudinal tear, also showed capillaries in the synovial tissue growing into the substance of the menisci, but they did not reach the tear (Figure 3). The tears with a quadriceps muscle graft, Dacron mesh, and the controls showed slight reactive vascularization in the periphery of the meniscus, but no capillaries were seen in the tear.

Discussion

In recent years, clinical experiments based on animal studies which promote meniscus healing in the avascular areas have been reported. Kimura et al. (1995) described their technique and the usefulness of meniscal sutures with a transplantation of the synovial pedicle flap in their clinical study. Henning et al. (1988) described their method of arthroscopic meniscal repair with a blood clot injection in the poorly vascularized area, but they did not mention the effect of their procedure in that clinical study. The procedures using free materials may be less invasive to the joint, and may be more frequently indicated than those which employ pedicle material. The normal shape, function and vascular anatomy of the canine meniscus are very similar to those of the human meniscus (Arnoczky and Warren 1982, 1983, Scheuer and Muhr 1988). The present study was designed to use a free synovium in the dogs' menisci, and was considered to be of clinical value for humans.

There have been a few reports of meniscal healing in avascular areas which were not dependent on the vascular supply from the adjacent synovium. Arnoczky and Warren (1988) filled a full-thickness hole with an exogenous fibrin clot in the avascular portion of the medial meniscus of dogs, and the defects healed due to proliferation of fibrous connective tissue. They reported that the fibrin clot appeared to act as a chemotactic and mitogenic stimulus for reparative cells, and provided a scaffolding for the reparative process. Webber et al. (1987) showed that the fibrochondrocytes in the meniscus of rabbits were capable of extricating themselves from their surrounding matrices and migrating into the fibrin clot scaffold, and that this biologic process required serum factors. These reports reveal that healing can occur without a vascular supply when fibrin and/or blood clot bridges the tears in the avascular portion of the meniscus. The stimulating factors in the serum, such as a platelet-driven growth factor, fibronectin, angiogenin, etc. (Arnoczky and Warren 1988, King and Vallee 1991), cells able to differentiate to reparative cells, and a scaffolding, seem to be essential for healing in the avascular part of the meniscus.

In the present study, the implanted synovium appeared to act as a scaffolding for the reparative cells in the tear. The synovium and meniscal tissue are thought to have been stimulated to provide the reparative cells by the blood in the implanted free synovium. The muscle graft is well vascularized and may have a scaffolding effect. The tears with the muscle graft and the Dacron mesh, however, showed no signs of healing or any neovascularization in the parameniscal areas. Therefore, neither the muscle graft nor the Dacron mesh can serve as a scaffolding or a source of cells capable of differentiating into reparative cells.

The healing rate in our previous report, using a flap of synovium, was 91% (Kobuna et al. 1995). The study using a fibrin clot achieved healing in 100%, without a vascular supply (Arnoczky and Warren 1988). However, only 11 of 35 menisci healed in the present study when a free synovial graft was employed. The vascular supply produced by the flap of synovium plays an important role in the process of healing, and it is easier for the free grafts than for the pedicle flaps of synovium to dislocate from the tears. The oval defect on the meniscus in the fibrin clot study is probably more stable than that of the longitu-

dinal incision in the present study. At 2 and 4 weeks of the present study, the free synovial graft remained in unhealed meniscal tears and, at 6 weeks or more, no free synovial graft was seen in the tears when they failed to heal. This shows that a meniscal healing process promoted by free synovium did not occur in the early stages, such as at 2–4 weeks, and that dislocation of the implanted synovium was a serious factor which disturbed the healing process.

Despite the poor healing rate and the fear that the strength of tissue at the suture site might not be restored to functional levels when a free synovium was used, our study shows that a free synovial graft can promote the healing process of tears in the avascular part of the meniscus. Gershuni et al. (1989) tried to improve the healing rate of tears in the avascular segment of canine knee menisci by implanting a vascularized synovial flap. They concluded that a higher percentage of tears healed when the knees were firmly immobilized and weight bearing was prevented. Immobilization and the prevention of weight bearing might prevent dislocation of the graft and increase the healing rate.

Acknowledgments

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