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ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION BY A VASCULARIZED AND INNERVATED GRAFT

An Experimental Study on Rabbits

By

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For the reconstruction of the anterior cruciate ligament, distally based fascia or tendon grafts (*Hey Groves* 1917, 1920, *Merle d'Aubigné* (according to *Ficat* 1962), *O'Donoghue* 1963, *Jones* 1963), proximally attached tendon grafts (*Lindemann* 1944, *Augustine* 1954), and even the meniscus (*Smillie* 1962) are used. Since it is obvious that distally based transplants have lost their blood supply and innervation, it may be assumed that they are of no more value than free transplants. On the other hand, dynamic ligaments, connected with muscle and formed by means of tendon transposition, are unphysiological owing to their muscular function.

In the present experimental study we have worked with tendon grafts in which neurovascular element is preserved but the muscular connexion is severed, our aim being to see how such a graft behaves when it is transposed intra-articularly to the site of the anterior cruciate ligament.

METHOD

The experimental animals were white rabbits of the same stock, and approximately the same age and weight (about 2½ kg). For the study 30 animals were used, 7 of which were lost at operation or because of postoperative infection. The rabbits were anaesthetized with intravenously adminstered Nembutal® (Abbott). Through an anterolateral incision in the left knee the joint was opened and the anterior cruciate ligament removed. The tendon of the semitendinosus muscle was separated from the medial condyle of the tibia and the tendon was tagged with a suture. The origin of the same muscle was separated with a knife from the ischial tuberosity (Figure 1). The purpose was to preserve the circulation and innervation of the muscle-tendon

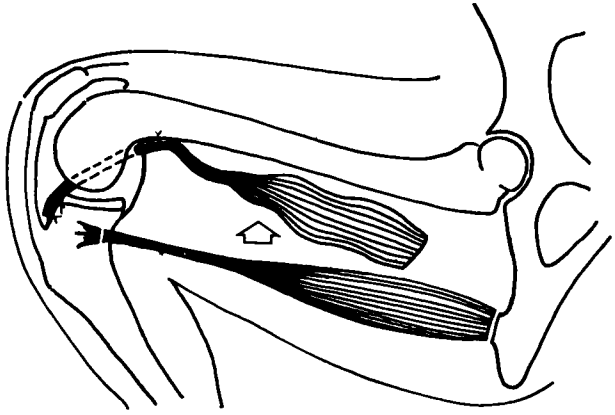


Figure 1. Operation. The semitendinosus muscle is freed at both ends. The tendon is transposed behind the femur and brought into the knee joint to the site of the excised anterior cruciate ligament.

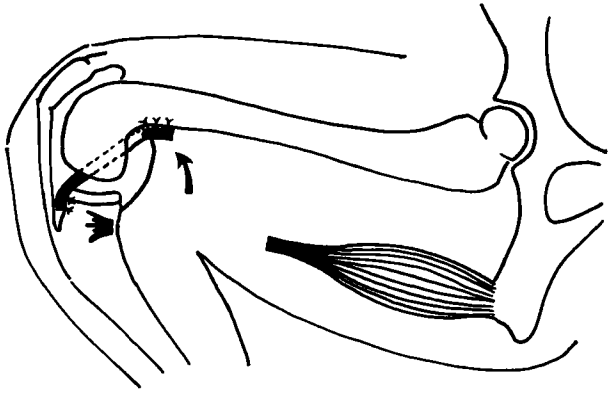


Figure 2. A free graft is taken from the tendon of semitendinosus muscle and fixed to the site of the excised cruciate ligament.

unit intact. The posterior capsule of the knee was opened at its femoral insertion and through this opening the freed tendon was pulled as atraumatically as possible through the joint. The distal end of the tendon was fastened to the tibial insertion of the anterior cruciate ligament and thence anteriorly with nylon or steel sutures. In some instances the tendon was attached with superficial sutures to the posterior femoral periosteum. The fate of the vascular system of the muscle was investigated by means of angiography.

For control, operations were made in which the same part of the tendon was transplanted as a free graft to the same site as described above, but with firm sutures at both ends (Figure 2). In addition, ligament construction according to Hey Groves' method was carried out in 2 cases (Figure 3). The operated limb was

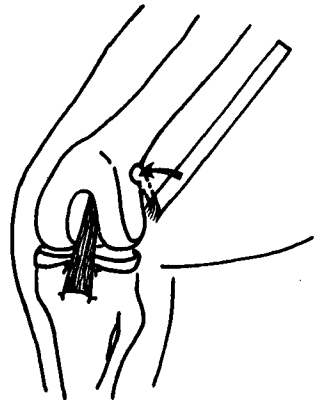


Figure 3. Hey Groves's reconstruction of the anterior cruciate ligament.

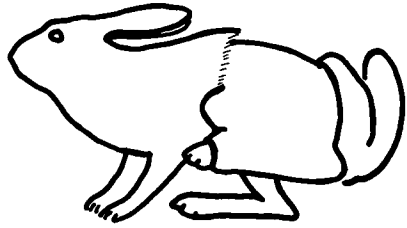


Figure 4. Immobilizing plaster cast.

immobilized with a plaster bandage around the trunk (Figure 4), which was removed after 3 weeks. Some animals tore off the bandage earlier.

The animals were sacrificed after periods of varying length. Angiography of their lower limbs was carried out as follows: The animal was heparinized *intra vitam* (2500 IU Heparin iv.). It was then killed with an intravenous overdose of pentobarbital. The abdominal aorta was exposed, cannulated and injected with Micropaque suspension (1 part Micropaque/2 parts water). Perfusion was continued for 45–90 minutes at a pressure of 80–90 mm Hg. An angiogram was then made of the entire hind part of the animal.

The reconstructed ligament with its muscles and the corresponding ligament and the semitendinosus muscle of the contralateral limb were freed. The distal ends of each ligament was marked with a suture and the freed muscle-tendon units were photographed on the same plate. The ligaments were placed in 10 per cent neutral formol. Paraffin blocks were made in the usual way. Longitudinal sections of the ligament, and transverse sections of both ends and of the centre of the ligament were made. The specimens were stained with haematoxylin-eosin, van Gieson and Gomori's trichromic staining.

In all, the series comprises 16 tendon reconstructions with pedicle grafts, 5 tendon transplantations with free grafts and 2 fascia lata transpositions according to Hey Groves (Tables 1–3).

Table 1. Results of transposition of pedicle grafts.

No.	Interval between reconstruction and taking of specimen weeks	Macroscopic finding	Histological finding	Remarks
1	4½	Good	Living tendon	
2	4½	Fair	Living tendon	Distal loosening
3	5	Good	Living tendon	
4	6	Good	Living tendon	
5	6	Poor	Infection	
6	9	Fair	Living tendon	Adhesions
7	9	Good	Living tendon	
8	10	Fair	Living tendon	Adhesions
9	10	Poor	Living tendon & degen. tendon	Distal loosening
10	10	Poor	Living tendon	Adhesions. Infection
11	11	Good	Living tendon	
12	13	Good	Living tendon	
13	13	Good	Living tendon	
14	17	Good	Living tendon	
15	21	Good	Living tendon	
16	24	Good	Living tendon	

Table 2. Results of free tendon grafting.

No.	Interval between reconstruction and taking of specimen weeks	Macroscopic finding	Histological finding	Remarks
1	5	Good	Degeneration & necrosis	
2	6	Good	Degeneration & necrosis	
3	6	Good	Degeneration & necrosis	
4	9	Fair	Degeneration & necrosis	Adhesions
5	13	Good	Degeneration & necrosis	

Table 3. Results of Hey Groves's reconstruction.

No.	Interval between reconstruction and taking of specimen weeks	Macroscopic finding	Histological finding	Remarks
1	5½	Good	Degeneration & necrosis	
2	5½	Fair	Degeneration & necrosis	

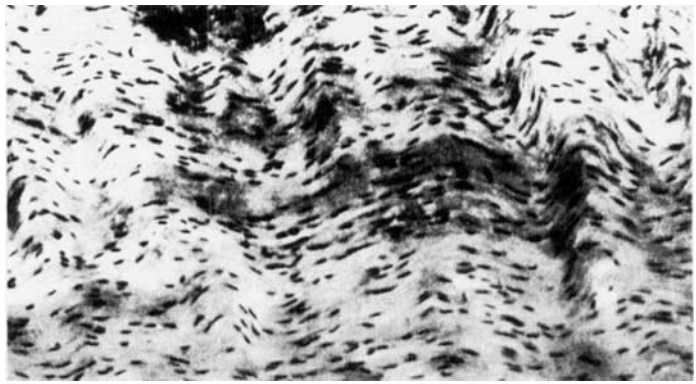


Figure 5. Normal tendon structure from a pedicle graft 9 weeks after transposition. × 120.

RESULTS

Gross examination showed that the innervation of the semitendinosus muscle appears to be preserved after detachment of the muscle and transposition of the tendon.

The macroscopic intra-articular findings varied. Sometimes the interior of the knee looked normal and sometimes there was a mass of adhesions and even infection. In Tables 1–3, the macroscopic finding 'good' indicates that adhesions, if any, were sparse and that the ligament appeared healthy, the knee more or less stable and the function of the limb satisfactory. 'Fair' indicates some intra-articular adhesions and that the ligament is somewhat loose. 'Poor' indicates abundant adhesions, infection and a ligament loosened from its site of attachment.

Evaluation of the functional result was uncertain, some animals used their leg freely, others less well.

HISTOLOGICAL FINDINGS

A. *Pedicle grafts.* In all reconstructed ligaments the structure of the tendon was normal and the graft was vital (Figure 5). In some specimens, near the distal insertion, there was waxy degeneration and scantiness of nuclei centrally. The tendon was, as a rule, vital throughout with preserved vessels in which Micropaque suspension was often seen. Whether some of these vessels came from the distal insertion or only along the tendon could not be seen. In experiments on dogs, *Peacock*

Figure 6. Loss of structure and homogenization of a free tendon graft 9 weeks after transplantation. × 120.

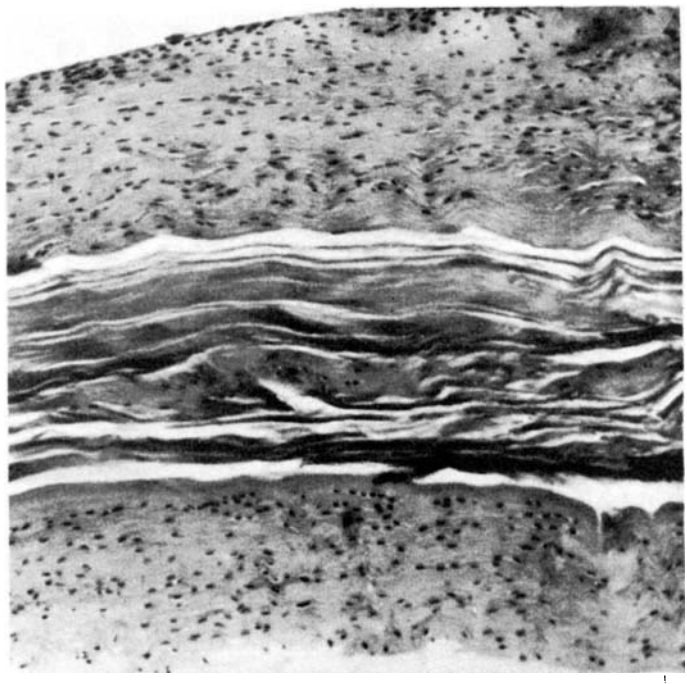
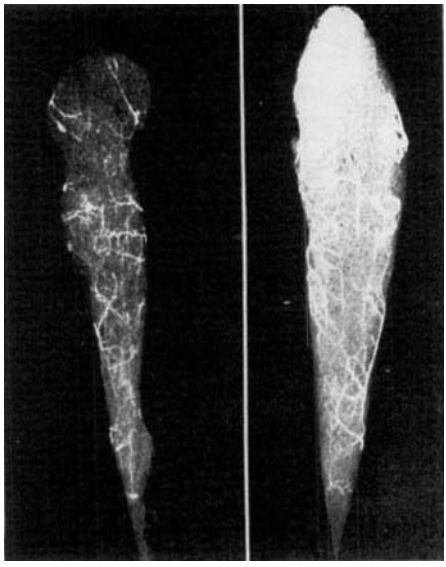


Figure 7. Necrosis of central portion of fascia transplant. Necrosis and disintegration in the periphery, 5½ weeks after Hey Groves's reconstruction. × 120.



A B

Figure 8. Example of angiograms of transposed muscle tendon unit (A) and of the corresponding structure of the intact limb (B). (Eleven weeks after the operation).

(1959) demonstrated that blood vessels entering long tendons from the muscular origin and periosteal insertion are able to nourish only the proximal and distal third of the tendon. The length of the tendon used in the present series is less than that of the digital flexors. From the histological specimens taken from transposed tendons it was, as a rule, impossible to conclude whether the graft had been in place for 4 or 24 weeks. When a longer period had elapsed since grafting, the synovial membrane covered the ends of the graft, and sometimes even the centre of it.

B. *Free grafts* and *fascia transplants*. After transplantation with free grafts and fascia there was never a picture of a normal tendon or fascia but only of marked degeneration, disintegrating tissue and necrosis as well as inflammatory cell infiltration. Many cells were polymorphonuclear leukocytes, lymphocytes and undifferentiated cells. Neither fibroblast proliferation nor collagenization could be demonstrated with certainty. Occasionally, necroses were seen and scar tissue, which replaced the necrosis without showing any tendency to form ligamental or tendon tissue (Figures 6–7). No vessels were seen in the transplants except capillaries at both insertions. Synovial membrane was seen on the surface of both ends of the transplants.

ANGIOGRAPHIC FINDINGS

Angiography was done in 13 cases. A filling was always obtained of the vessels of the muscle, detached at its origin or tendon (Figure 8). In none of the muscle-tendon units of the intact hind legs did the blood vessels in the area of the tendon fill with contrast medium, while even in the distal end of three pedicle grafts, and in two cases even along the tendon, a thin pattern of vessels was seen which, owing to the faintness of the picture, cannot be reproduced here. These findings were verified in the histological specimens. In none of the cases of free grafting could vascularization be demonstrated at angiography, neither could this be done in the Hey Groves transplant. Unfortunately, microangiography proved unsuccessful.

DISCUSSION AND CONCLUSIONS

When an error in the technical performance or infection did not cause complications, the result of transposition with pedicle grafts, *i.e.*, intra-articularly transposed grafts with preserved neurovascular elements, was microscopically and histologically good. However, free grafts and the fascia transplants comparable with them did not remain vital. The free grafts often seemed macroscopically healthy but histologically they appear to form fibrotic scar tissue only. When transferred into a joint, the free grafts do not become adequately vascularized from their surroundings soon enough. For the assessment of the final fate of the graft the period of observation is short. As regards function, the anterior cruciate ligament of the rabbit cannot be compared with that of man.

SUMMARY

A preliminary investigation on reconstruction of the anterior cruciate ligament of the rabbit is described. Only pedicle grafts with preserved vascularization and innervation remained vital, while degeneration, necrosis and fibrosis occurred after transplantation with free grafts or distally based fascial strips.

RESUME

Une recherche préliminaire sur la reconstruction du ligament croisé antérieur chez le lapin est rapportée. Seules les greffes à pédicule préservant le vascularisation et l'innervation sont restées vitales, alors que

la dégénération, la nécrose, apparaissent après transplantantion de greffes libres ou de lambeaux de fascia de bases distales.

ZUSAMMENFASSUNG

Eine vorläufige Untersuchung der Wiederherstellung des lig. cruciatum anterius des Kaninchens wird beschrieben. Nur gestielte Transplantate mit erhaltener Gefässversorgung und Innervation erhielten sich lebenstüchtig, während Degeneration und Nekrose von freien Transplantaten oder distal gestielten Fascienstreifen entstand.

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