RECONSTRUCTION OF THE ANTERIOR CRUCIATE LIGAMENT BY
ALLOGENEIC TENDON GRAFT

AN OPERATION FOR CHRONIC LIGAMENTOUS INSUFFICIENCY

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We describe the use of allogeneic human tendon as an intra-articular replacement for the anterior cruciate ligament. Depending on the type and degree of functional instability we recommend the addition, in some cases, of supplementary extra-articular procedures.

We have reviewed 31 patients at least two years after operation and have found that 30 of them had been able to return to full sporting activities. The indications for operation and the techniques are discussed and the use of allogeneic tendon is recommended.

Anterior cruciate ligament injuries often lead to significant disability. Various operations have been described for instability due to ligamentous insufficiency (Jacobson 1977; Marshall et al. 1978; Feagin 1979; Fetto and Marshall 1980). Most commonly, autologous tendon or fascia have been used, either pedicled or free (Hey Groves 1919–20; Jones 1963). The functional amount of tissue available for transfer is limited by the fear of creating a defect at the donor site. It would therefore be useful if allogeneic tendon could be used to substitute for the anterior cruciate ligament.

Encouraged by our study of allogeneic tendon as a replacement for the anterior cruciate ligament in the dog (Shino et al. 1984b), we started the clinical use of allografts in 1981. We now report the early results of anterior cruciate reconstruction with allogeneic tendons in 31 patients.

MATERIALS AND METHODS

Between 1981 and 1984, 83 patients had our new operation for chronic insufficiency of the anterior cruciate ligament, and 31 of them have been personally reviewed after a minimum follow-up of 24 months (mean 31 months, maximum 40 months). There were 18 men and 13 women with an average age of 25 years (range 18 to 46 years). The average time from the initial injury to the operation was 24 months. All except three patients had sustained the initial injury during sporting activities including basketball, skiing, volleyball, athletics, rugby football, soccer, baseball, gymnastics, softball, judo and sumo wrestling. Of these, 13 injuries were sustained at a competitive level and 13 at a recreational level, while two gymnastic instructors were injured while teaching. Before operation, instability had prevented any of the competitive athletes from returning to their original level of sport, and they were only able to attempt recreational sport at best.

The chief complaint of 25 of the patients was multiple episodes of giving way. The other six patients complained of instability during normal activity and could play no sport. Three patients presented with a locked knee after many episodes of giving way. One patient had had repair of a medial meniscus, but this had failed to improve her chief complaint of giving way.

Our criteria for reconstruction of the anterior cruciate ligament were functional instability during daily activities or sport at recreational level, and a moderate to severe positive Lachman sign that reproduced the sensation of instability (Torg, Conrad and Kalen 1976). We also used stress radiographs to measure the anterior movement of the tibia in comparison with the contralateral normal knee. Since September 1983, we have also used our clinical knee-testing apparatus to evaluate anteroposterior instability (Shino et al. 1984a).

Extra-articular augmentation on the lateral side (iliotibial band reinforcement) was used in cases in which the markedly positive pivot shift sign replicated the giving-way sensation (Galway and MacIntosh 1980; Shino et al. 1983). Extra-articular augmentation on the medial side, by pes anserinus transfer, was used where there was a positive anteromedial rotatory instability test (Slocum and Larson 1968a,b). If the test was moderately to severely positive, a modified Mauck procedure or

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posteromedial imbrication was combined with the pes anserinus transfer (Mauck 1936).

All patients had double-contrast arthrography before operation to evaluate lesions of the menisci and the articular cartilage, and then vigorous rehabilitation. They were taught how to land after jumping or turning, and how to avoid sudden stops (Noyes et al. 1983b). They were also advised to give up competitive and contact sports. If the patient showed little improvement in stability of the knee or had a strong wish to return to competitive or contact sports, then the operation was advised. The goal of operation was to restore enough functional stability to allow recreational sport, with the possibility of return to competitive level for those without significant degenerative changes.

If the patient also had symptoms such as locking or effusion caused by a torn meniscus, a decision on the need for anterior cruciate reconstruction in addition to a meniscus operation was based on the expected functional level and the anticipated type of sporting activity. In our opinion, active young athletes who have both a torn anterior cruciate ligament and a posterior meniscal tear should have ligament repair and not only meniscectomy or meniscus repair (Levy, Torzilli and Warren 1982; Paterson and Trickey 1983).

In addition to their moderately or severely positive Lachman sign, 29 of the 31 patients had significant valgus laxity at 30 of flexion, and seven had mild valgus laxity in full extension. No patient showed significant varus laxity, but all except one of the patients had a markedly positive pivot shift test. All except two patients had some anteromedial rotatory instability (Slocum and Larson 1968a) and again, all but two had slight or mild anterolateral rotatory instability as determined by the drawer test with the tibia in 30 of medial rotation (Hughston et al. 1976). Pre-operative radiographs of all the patients were normal, with no significant degenerative changes other than marginal osteophytes in the intercondylar notch.

At operation all patients were noted to have either an absent or a severely attenuated, non-functioning anterior cruciate ligament. The medial meniscus was found to be torn in 16 patients and the lateral meniscus in five. The medial collateral ligament was significantly elongated in five patients, and the posterior oblique ligament was torn or significantly elongated in two. Degenerative changes with erosion of the joint surfaces were seen in 10 patients; these changes were in the medial compartment in three patients, in the lateral compartment in three, and in both compartments in four. Significant degenerative changes were seen in the patellofemoral compartment in three patients.

**TECHNIQUES**

**Graft collection.** Allogeneic tendons were harvested, using sterile techniques, from non-infected amputation specimens or fresh cadavers within two hours of amputation or death. The donors were between 16 and 80 years of age.

The allogeneic tendons were grouped or divided to provide grafts 8 to 9 mm in diameter and at least seven cm long. Each was enclosed in a sterile airtight tube and stored at -80°C for at least 10 days before use. The most commonly used donor tendons were half of the tendo calcaneus, the tendon of tibialis anterior, and a group of several flexor tendons.

**Intra-articular operation.** The knee is inspected through a medial parapatellar incision and any associated damage to menisci is treated by partial meniscectomy or meniscus repair. Eroded articular surfaces are drilled or shaved. The remnants of the anterior cruciate ligament are excised to expose the posterior border of its femoral attachment, and any intercondylar osteophytes and the tibial spines are removed to prevent impingement on the graft during extension movements (Norwood and Cross 1977).

Drill holes are then made in the tibia and femur. A Kirschner wire is drilled from a point just medial to the tibial tubercle to emerge at the anteromedial edge of the original tibial attachment of the anterior cruciate ligament, and this is overdrilled with an 8 mm cannulated reamer. With the patella dislocated laterally and the knee flexed to over 100°, another Kirschner wire is drilled from the posterosuperior edge of the femoral attachment of the original ligament to emerge on the lateral femoral cortex just above the lower end of the linea aspera. This wire is also overdrilled with the reamer.

An 8 mm trial ligament of woven Dacron is then drawn into place and used to confirm that the reconstructed ligament will be tight throughout the range of movement. If the drill holes have been well situated, the necessary change in the length of the ligament should not exceed 3 mm throughout the entire range of movement.
The position of the drill holes may need correction at this stage.

A freeze-stored allogeneic tendon is selected and kept at room temperature for ten minutes in saline with added antibiotics. The surrounding paratenon and fatty tissues are removed as completely as possible and thick polyester (Tevdek) sutures are placed in each end. These sutures are led through the drill holes and tied over buttons at the correct tension with the knee flexed at 40 to 60°. Care should be taken that at least 1.5 cm of the free ends of the graft are entirely within the bone. If the graft is long enough, then staples with spikes on the under-side of their bridges can be used to secure fixation (Fig. 1).

**Extra-articular operation.** To correct mild anteromedial rotatory instability, a pes anserinus transfer is performed. If this instability is moderate to severe and there is significant valgus laxity, then either a modified Mauck procedure for distal advancement of the superficial medial collateral ligament (Fig. 2) or postero-medial imbrication of the damaged posterior oblique ligament is added to the pes transfer (Hughston and Eilers 1973).

To correct moderate to severe anterolateral rotatory instability, as shown by a markedly positive pivot shift test, we have designed a new iliobibial band reinforcement. Through a lateral longitudinal incision curved across Gerdy's tubercle a strip of the iliobibial band, free distally and ending with a button of bone, is raised (Ellison 1979). The biceps femoris muscle is then freed from the common peroneal nerve, moved anteriorly, and the tendinous portion of the long head is incised longitudinally. The freed strip of iliobibial band is passed through the split biceps tendon and sutured to it at the level of the lateral femoral epicondyle (Fig. 3). The distal part of the iliobibial band, now more horizontally orientated, is reattached by replacement of Gerdy's tubercle with a staple. This technique not only gives a horizontal direction to the distal part of the iliobibial band but also creates an extra anterior insertion by which the biceps femoris muscle can act against anterior subluxation of the lateral tibial plateau.

**Postoperative management.** A toe-to-groin cast is applied with the knee flexed 40 to 50°. It is retained for six weeks but shortened to a cylinder for the last two weeks. Vigorous active flexion exercises begin immediately after removal of the cast but extension beyond 30° is not allowed for another four weeks, and weight-bearing is forbidden for another seven weeks. The muscle-strengthening programme is directed mainly to the hamstrings, with less attention to quadriceps exercises in 90° of flexion. Manipulation under anaesthesia is performed at six to seven months if flexion has not reached 130° or if extension lacks more than 15°. In our whole series of patients, manipulation under anaesthesia was necessary in only about 3% of the knees. Patients were recommended to start jogging after eight months, and return to other forms of athletic activity was allowed after 11 to 12 months.

**RESULTS**

Of the 32 patients who had been followed-up for over 24 months, 31 were available for personal evaluation by two of the authors (KS and TK), all the operations having been performed under the supervision of KS. All but three of the patients had been evaluated biomechanically by our clinical knee-testing apparatus (Shino et al. 1984a) and 16 had had arthroscopies under spinal anaesthesia at 3 to 30 months after operation.

None of the patients had had any episodes of giving way during activities of daily living or of any type of sport. Thirty patients had returned to full sporting activi-
ties including basketball, volleyball, skiing and tennis. Four patients had returned to a highly competitive level of sport in rugby football, basketball, softball and skiing. The two gymnastic instructors had resumed their original occupation, and two patients had resumed heavy manual labour without fear or difficulty.

Patients were asked whether they considered the knee to be completely normal, or to be improved, the same, or worse than before operation. In all, 18 patients replied that the knee was normal, 12 that it was improved, and one stated that it was worse.

All the patients had a clinical examination and radiographs were taken to assess any abnormal response of the bone to the allogeneic tendons. No patient had any evidence of effusion, synovial thickening, or skin necrosis which would suggest rejection of allogeneic tendon. Measurement of the circumference of both thighs 10 cm above the patella showed no residual muscle wasting in nine patients, under 1 cm in 15, 1 to 2 cm in five and 2 to 3 cm in two. The range of movement was normal in 16 patients, with less than 5° loss of extension in 11 patients, loss of 5° to 10° in one and 10° to 15° in three. There was loss of flexion in only one patient, by 10° to 15°.

The Lachman sign was negative in 26 patients, barely positive in three and mildly positive in two. The pivot shift sign was negative in 29 patients, and slightly to mildly positive in two patients whose contralateral normal knees also showed a mildly positive sign without any episodes of giving way. No patient during these tests showed the apprehension which had commonly been present before operation. Varus instability was not changed by operation but valgus instability had been improved in those who had had medial tightening.

The functional results were graded as excellent in 24 patients, good in six and fair in one: no patient was graded poor. An excellent result was one in which the patient had been able to return to all desired or previous activities (including sport or manual labour) without any giving way or effusion and with no pain or only very rare pain. A good result was one in which the patient had returned to all desired or previous activities without giving way or effusion and with only occasional pain, felt only on strenuous and not on normal activities. A fair result was one in which the patient was restricted to less strenuous activities by significant pain.

Radiographs taken at six weeks, one year and two years after the operation showed no evidence of abnormal bone responses; the drill holes had become less obvious with time (Fig. 4).

Arthroscopy revealed no abnormal responses in the

![Figure 4](image)

An anteroposterior radiograph taken two years after operation. Note that both femoral and tibial drill holes are already invisible, and that there are no abnormal responses of the bone to the allograft.

![Figure 5](image)

![Figure 6](image)

![Figure 7](image)

Arthroscopic views of allografts at various periods after operation (LC, lateral femoral condyle; G, graft). Figure 5 After six months the replacement has a taut and thick appearance, with its surface more richly vascularised than the normal anterior cruciate ligament. Figure 6 After 12 months the reconstructed ligament has a functional appearance, and the early hypervascular response has subsided. Figure 7 After 30 months the ligament looks thick and taut with superficial vascularity similar to that of the normal anterior cruciate ligament.
Fig. 8

Figure 8 Diagram of our apparatus for the clinical evaluation of antero-posterior instability of the knee. The patient reclines with the knee flexed to 20°. The distal thigh is fixed to the apparatus, then the proximal calf is displaced anteriorly and posteriorly while movement of the tibia with respect to the femur is recorded by two transducers, one on the tibial tubercle and the other on the anterior surface of the patella. Force and resulting displacement are plotted on a recorder. Figure 9 Result obtained from the apparatus. Anterior stiffness at 50 N and anterior laxity at 200 N can be read from the anterior loading curve.

synovial membrane, rich revascularisation of the allografts at three to six months and adequate vascularisation at 12 to 30 months. The grafts were taut and massive, and were seen to function well against anterior drawer stress applied to the tibia (Figs 5, 6 and 7).

Biomechanical evaluation at 20° flexion by our clinical knee-testing apparatus (Figs 8 and 9) revealed that anterior stiffness of the 28 knees at 50 N was $2.3 \pm 1.3 \times 10^4$ N/m, and that anterior laxity at 200 N was $8.6 \pm 3.3$ mm. These values were not significantly different from those obtained for the contralateral normal knees (Figs 10 and 11). The mean anterior stiffness of the normal knees at 50 N was $2.0 \pm 0.9 \times 10^4$ N/m; anterior laxity at 200 N was $9.1 \pm 4.2$ mm.

Complications. There were no deep infections and no signs of rejection such as prolonged fever or abnormal laboratory findings, though no immunosuppressives or corticosteroids had been given. Two patients had superficial staphylococcal infection around alumina ceramic pull-out buttons. One patient, the only result graded fair, had a stiff knee which required re-operation to release intra-articular adhesions. At follow-up the range of movement was from 15° to over 130° and was still improving.
DISCUSSION

There is still major controversy over the long-term effects of insufficiency of the anterior cruciate ligament. Many clinical studies have confirmed that patients with insufficiency are very likely to tear one meniscus (50% to 78%) or both menisci (38%) (Jacobsen 1977; Feagin 1979; Ietio and Marshall 1980; Clancy et al. 1982; Noyes et al. 1983a). This results in degenerative changes which may be seen at operation or, in the longer term, on radiographs. By contrast, some patients with anterior cruciate insufficiency can enjoy sport without functional instability and have neither meniscal tears nor early degenerative changes (McDaniel and Dameron 1980; Balkfors 1982; Hughston and Barrett 1983).

In the remainder of this discussion we attempt to answer a number of key questions.

Which patients with anterior cruciate insufficiency require a reconstructive operation? Most of our patients had had multiple episodes of instability of the knee which had resulted in meniscal tears or significant degenerative changes or both. Of our 31 patients, 25 (81%) had torn at least one meniscus, and 14 (45%) had significant degenerative change in the articular cartilage. These facts suggest that patients with chronic knee instability are highly likely to develop early degenerative changes.

Therefore, active young athletes who have sustained a tear of the anterior cruciate ligament and have a strong wish to continue vigorous sports which include jumping, sudden turning or body contact, must benefit from early operation. In our series, a 28-year-old male basketball player, operated on three months after his initial injury, was able to return to competitive basketball as a first-class player 11 months postoperatively.

Is an intra-articular reconstruction necessary? We consider that intra-articular reconstruction is essential for two reasons. First, because it provides the primary restraint against excessive anterior translation of the tibia with respect to the femur, as has been shown in experimental studies on cadaveric knees (Butler, Noyes and Grood 1980; Fukubayashi et al. 1982), and secondly, because functional instability in these patients is not always fully corrected by extra-articular operations (Kennedy, Stewart and Walker 1978; Ireland and Trickey 1980).

Are additional extra-articular procedures needed? We believe they are. The reconstructed intra-articular ligament consists of only one thick bundle, as against the bundles with different functions seen in the normal anterior cruciate ligament (Kennedy. Weinberg and Wilson 1974; Norwood and Cross 1979). In addition, capsular laxity secondary to recurrent subluxation is common in chronic insufficiency. We feel that every type of instability and laxity should be corrected as completely as possible at the time of operation to protect the graft from excessive stress.

The iliotibial band reinforcement which we use to augment repair in the presence of anterolateral instableility is a modification of the Ellison procedure. It provides a horizontally-orientated reduction force, and this is aided by the power of the biceps femoris muscle which contracts as an antagonist to the quadriceps when the patient stops or turns suddenly. The efficacy of this procedure has been confirmed by our previous electromyographic studies (Shino et al. 1983). The efficacy of pes anserinus transfer for anteromedial instability is well established (Perry et al. 1980).

What is the best substitute for the anterior cruciate ligament? Part of the extensor mechanism, such as one-third of the patellar ligament or part of the quadriceps tendon, has been widely used to replace the anterior cruciate ligament, mainly because of ease of access and adequate tensile strength (Noyes et al. 1984). However, such removal must weaken the donor tissue and may lead to functional disability, especially in athletes (Bonamo, Krinick and Sporn 1984). Consequently, various types of artificial ligament and heterologous bioprotheses have been developed, but clinical trials of these materials have proved that they can provide neither a long-standing prosthetic substitute nor an innocuous scaffold which will induce thick fibrous tissue (Rushton, Dandy and Naylor 1983; Teitge and Rojas 1984).

Various allogeneic fibrous tissue grafts have been successfully used in orthopaedics. Neviaser, Neviaser and Neviser (1978) reported the successful use of freeze-dried allogeneic rotator cuff to repair massive chronic ruptures of the rotator cuff of the shoulder. There were no graft rejections and improved movement and relief of pain were usually attained. At re-operation the graft was noted to be completely reorganised as a viable rotator cuff. Bright and Green (1981) also reported the clinical use of freeze-dried fascia lata allografts in various types of orthopaedic reconstruction. The successful clinical use of tendon allografts in reconstruction of the hand has also been reported, though with a variety of methods and preservatives (Flynn et al. 1960; Iselin, De La Plaza and Flores 1963; Peacock and Madden 1967). These reports suggest that allogeneic fibrous tissues such as tendon or fascia have too little antigenicity to provoke immunological rejection.

Allogeneic tendon may prove to be one of the best substitutes for the anterior cruciate ligament, provided that the immunological response in humans is as negligible as in dogs (Shino et al. 1984b).

What is the best way of treating and preserving allogeneic tendon? Treatment should prevent bacterial or fungal infection but should not weaken the allograft. It should reduce immunological antigenicity. Freezing is a widely accepted method for preserving allograft bone and, at −80°C, prevents infection. It does not alter the mechanical properties of ligaments (Noyes and Grood 1976).

As to its effect on antigenicity, Minami et al. (1982) showed, in experiments on rats, that allogeneic tendon had major histocompatibility antigens found mainly in tendon–cell components, and that treatment by freezing
and thawing decreased the antigenicity more effectively than irradiation, glutaraldehyde or mitomycin C. Our study in dogs also showed that allograft tendons which had been treated by freezing and thawing before being used to replace the anterior cruciate ligament were revascularised and remodelled like autografts, with no histological evidence of immunological rejection. Furthermore, a study using immunofluorescence techniques also demonstrated that the antibody response to an allograft tendon was very much inhibited by storage at ~80°C (Rodrigo et al. 1985).

For these reasons, freezing and thawing is considered to be the best treatment for allograft tendons, provided that there is no risk of contamination. Accordingly, we chose donors who had neither infectious disease nor contaminated wounds. Freeze-drying was not used because of the fear that it might reduce the mechanical strength of the tendons.

_Does an allogeneic tendon graft eventually function as a viable ligament which can resist repeated tensile stresses?_ Arthroscopy clearly showed that the grafts were thick, taut and adequately revascularised from three to 30 months postoperatively, and that neither degradation nor absorption had occurred. Our biomechanical evaluation demonstrated that most of the repaired knees had practically normal mechanical parameters in anterior loading curves, although most patients were young athletes who had been active in various sports from 10 to 12 months after operation. No patients became worse during follow-up. These facts suggest that the grafts function as viable ligaments from the sixth postoperative month. Furthermore, sections of a biopsy obtained 17 months after grafting clearly showed that the reconstructed ligament had been elaborately remodelled and was viable (Figs 12 and 13).

**How should valgus instability be corrected?** The modified Mauck procedure was used with a view to preserving the function of the medial meniscus. It stabilised the medial side of the knee satisfactorily because the superficial part of the medial collateral ligament provides the primary resistance to an applied valgus stress (Grood et al. 1981). We consider that elaborate reefing of elongated capsular structures is likely to disturb the peripheral attachment of the medial meniscus.

**Conclusions.** The method described provides functional stability to patients with symptoms of anterior cruciate ligament insufficiency. It does not involve the sacrifice of any autologous tissue and was successful in first-class competitive athletes.

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**REFERENCES**


