PROSTHETIC ANTERIOR CRUCIATE LIGAMENTS
IN THE RABBIT
A COMPARISON OF FOUR TYPES OF REPLACEMENT

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Four types of prosthetic replacement for the anterior cruciate ligament (carbon fibre, carbon fibre and Dacron composite, Dacron alone and bovine xenograft) were assessed at three, six and 12 months after implantation in the knees of New Zealand white rabbits. The synovium and both intra-articular and intra-osseous portions of the ligaments were examined macroscopically, by light microscopy and by scanning electron microscopy.

All the knees showed mild synovitis, and there was no significant growth into the intra-articular part of any ligament. Carbon fibre and xenograft did not appear to be suitable materials in this animal model. The composite ligament showed short-term ingrowth of fibrous tissue only into the periphery of the sheath in its intra-osseous portion, whereas the Dacron ligament showed progressive fibrous tissue ingrowth with some bony incorporation of its outer fibres.

The first use of a prosthetic anterior cruciate ligament was 80 years ago, but it is only in the last 15 years that they have been used in significant numbers. This arises partly from the increased frequency of anterior cruciate ligament injury and consequent disability, and partly from dissatisfaction with the results of autologous repair operations for instability. The latter often require a long rehabilitation period and may have a 30% to 40% failure rate at five years (Odensten, Lysholm and Gillquist 1983; Friedman et al. 1985).

A wide range of materials is available to replace or augment the anterior cruciate ligament. These include polydioxanone, nylon, polypropylene, expanded polytetrafluorethylene, Dacron (polyethylene terephthalate) or polyester, carbon fibre, tendon or ligament xenografts, and various combinations of synthetic materials. There are few reports of the results of animal experiments and clinical data often conflict. We have examined the biological response to four different prosthetic materials in rabbits’ knees with emphasis on intra-articular and intra-osseous reactions.

MATERIALS AND METHODS

The four types of prosthetic ligament we used are shown in Figure 1.

The carbon fibre ligament comprised three tows, each of 5000 filaments of uncoated, high-strength dry carbon fibre.
The carbon fibre/polyethylene terephthalate composite (Westminster ligament) comprised 40,000 filaments of the same uncoated, high-strength dry carbon fibre. This tow was drawn into a braid of ICI terylene delustered polyester. Each end consisted of 92 filaments assembled with an S-twist and each ply consisted of 92 filaments assembled with a Z-twist. The filament diameter was approximately 15 μm.

The polyethylene terephthalate (Dacron) ligament was of 4 mm high-strength type, with each tip tubed in polyethylene for easy insertion. The outer sheath was a tube of knitted, double-velour Dacron sewn at four corners to give an “H”-beam envelope which contained a core of four woven Dacron tapes.

The xenograft was a bovine tendon whose natural intermolecular cross-links had been treated with glutaraldehyde. The resultant stabilised collagen was theoretically resistant to mechanical, chemical and biological degradation, and it was claimed that it would form a true biological prosthesis.

In all, 24 female New Zealand white rabbits of age between six and 12 months were used, six for each type of ligament.

**Technique of operation.** General anaesthesia was induced using 4% halothane by mask, and maintained with a 2% mixture. The fur was shaved from the right lower limb and the skin prepared with aqueous chlorhexidine. A medial parapatellar incision and approach allowed the patella to be dislocated laterally. The anterior cruciate ligament was identified and excised. Drill holes were made in the femur and tibia at the “anatomical” attachments and the prosthetic ligament was introduced. It was sutured with absorbable sutures at the exit of the drill holes, in moderate tension with the knee in 15° of flexion. A dressing was applied and the leg held in an elastoplast dressing for 10 days.

Eight rabbits were killed at each of three, six and 12 months from operation so that there were two animals in each ligament/time subgroup.

Transverse and longitudinal sections were made of each ligament in both its intra-articular and intra-osseous course. These, and sections of the synovium, were stained with haematoxylin and eosin and, where appropriate, Miller’s stain. Conventional microscopy was used, with the addition of scanning electron microscopy for the majority of the sections.

**RESULTS**

**Carbon fibre. Intra-articular.** The ligament had ruptured completely in its intra-articular portion in all six animals and there was no evidence of any “neoligament” formation. The synovium in the three- and six-month specimens showed heavy carbon staining, but this was less marked at 12 months.

**Intra-osseous.** At three months collagen was growing between the carbon fibres and there was a fibrous-tissue cuff approximately 600 μ thick between the bone and the carbon fibre (Fig. 2). At six months this layer appeared to be between 150 μ and 400 μ thick and a cuff of lamellar bone almost surrounded the carbon fibre tow. At 12 months this cuff approached the tow more closely. Both individual fibres and groups of them were incorporated into this matrix, but some fibres were seen remote from the site of the implant. The carbon fibres had become more separated and were infiltrated with fatty marrow and fibrous tissue, but no complete haversian systems were seen in the tissue growing into the carbon fibres despite the presence of the cuff of lamellar bone.

**Carbon fibre/Dacron composite (Westminster ligament). Intra-articular.** Four ligaments were intact, one had an incomplete rupture at six months, and one a complete rupture at 12 months. Where there had been a rupture,
the synovium was heavily stained with carbon. In the other specimens the synovium was macroscopically normal with mild synovitis on microscopy.

Intra-osseous. At three months the fibroblastic material seen around the prosthetic sheath was confirmed to be collagen by Miller's stain (Fig. 3). There was a little microscopic ingrowth; this was confirmed by scanning electron microscopy. There was no progression at six months and at 12 months the fibrous tissue sleeve was seen to conform to rather than to penetrate the sheath of polyethylene terephthalate (Fig. 4).

Dacron. Intra-articular. Four specimens were intact, and two had sustained small partial ruptures. At six and 12 months a white film of variable thickness covered the ligament but there was no evidence of significant ingrowth. The synovium was macroscopically normal, though microscopy showed mild non-specific inflammatory changes such as hyperaemia and increased blood vessel formation.

Intra-osseous. At three months there had been fibroblastic tissue ingrowth into the periphery of the sheath, the outermost fibres being spread apart by fibrous tissue with some prosthetic fibres embedded in bone. At six months the ligament was enveloped in a richly vascular connective tissue with multinucleate giant cells and macrophages while its outer coat had become more diffusely infiltrated by fibrous tissue (Fig. 5). At 12 months there was almost complete dispersion of the fibres at the interface with a continuation of ingrowth which seemed to push apart but not penetrate the central tapes. Although this ingrowth was not bony in nature, some of the outer fibres were incorporated in bone (Fig. 6).

Bovine xenograft. Intra-articular. Three ligaments were intact and three showed partial rupture. No ingrowth had occurred in any specimen (Fig. 7). The synovium was macroscopically normal, though a mild synovitis was present macroscopically in all specimens.

DISCUSSION

The materials tested in this study have all been in clinical use and their biocompatibility has been established, but the reaction to each of them was different.
The mechanical strength and biological inertness of carbon fibre were the features responsible for its initial choice by Jenkins, who showed its potential as a biodegradable ligament scaffold at extra-articular sites in sheep (Jenkins et al. 1977). Some workers have coated the carbon fibre for easier handling and to prevent early degradation (Alexander et al. 1982; Weiss et al. 1985) while others have used it in an extra-articular position to augment an autologous repair (Lemaire 1985). It has not been clearly established whether "neoligament" formation could reliably occur in an intra-articular situation (Jenkins 1985; Görecki, Kuś and Salomon 1986).

The safety of Dacron has been confirmed by 20 years’ experience in cardiovascular surgery (Turner, Hoffman and Weinberg 1982). The observation that dense fibrous tissue grew into vascular grafts instigated a modification in their structure which resulted in improved strength, and this material was tested as a natural clefts within the graft material, and bovine xenograft used to replace the anterior cruciate ligament had been incorporated within the bony tunnels (McMaster 1985). Short-term clinical successes have been reported (Abbink and Kramer 1986), though longer follow-up has not been as satisfactory (Good, Odésten and Gillquist 1985, unpublished data).

The finding of generalised synovitis in these rabbits’ knees indicates a response to foreign materials which was variable but always present. It was interesting that there was less response to liberated carbon fibre after one year than at three months. No carbon fibre was found in any of the lymph nodes examined. All four prosthetic ligaments showed a disappointing amount of tissue ingrowth into their intra-articular portions, indicating that this behaviour is much less likely than at extra-articular sites.

Within the bony tunnels fixation is a key factor in long-term results. Response was slow with all materials and ingrowth, when it occurred, was predominantly fibrous although occasional areas of bony ingrowth were seen. Fibrous tissue invaded the carbon fibre, but was virtually absent in the xenograft and did not progress in the composite Westminster ligament. Further comments on these findings should await mechanical testing of the bone–ligament–bone system. The Dacron coat of the Westminster ligament has now been given a more open weave for clinical use.

The scope of our study was limited by the use of a small animal and some work with larger animals has started, so that prostheses of the standard “human” size can be tested. From our preliminary work we consider that uncoated carbon fibre is not a suitable replacement for the anterior cruciate ligament, mainly because of its failure to produce a “neoligament” before it disintegrates. The long-term effects of carbon on the synovium are probably benign though the appearance may worry the surgeon at re-operation (Rushton, Dandy
and Naylor 1983). Bovine xenograft appeared to produce relatively little reaction at either intra-articular or intra-osseous sites even after 12 months, except in one animal. The outer Dacron coat of the composite Westminster ligament appeared to have too tight a weave to allow adequate ingrowth at either site, so the basic design hypothesis remains untested. The Dacron ligament showed progressive fibrous tissue ingrowth at least into its sheath in its intra-osseous part, though the intra-articular response was variable.

Before there is even more widespread clinical use of intra-articular prosthetic replacements for the anterior cruciate ligament, we consider that their biological and mechanical properties should be more fully investigated. The placing of these materials under weight-bearing conditions in an intra-articular environment places heavy demands on them, not only in terms of biological reaction, but also in the mechanical factors of strength, creep, and bending fatigue.

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