BIOLOGICAL RESPONSE TO WOVEN CARBON FIBRE PADS IN THE KNEE

A CLINICAL AND EXPERIMENTAL STUDY

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We assessed the use of woven carbon fibre pads to resurface osteochondral defects in animals and in patients. The pads became filled with structurally strong and compliant fibrous tissue and did not provoke a synovial reaction, though pigmentation was induced in some animals. Of the patients, 77% had a satisfactory response to resurfacing, with no synovitis. Our initial experiments indicate that carbon pads may provide a satisfactory treatment for localised articular defects.

We have used carbon fibre in the form of a loosely-woven pad to repair osteochondral defects of the knee in over 400 patients. Carbon in its pure form was selected because of its apparent non-reactivity to living tissues compared to other materials such as silicon (Engkvist and af Ekenstam 1982), nylon (Kuhns 1964), polytetrafluorethylene (Trail, Frank and Minns 1986) and collagen sponge (Speer et al 1979). Carbon pads also proved simpler to use than periosteal grafting with autologous tissue (O'Driscoll and Slater 1986) or meniscal fibrocartilage (Heatley and Revell 1985).

We have previously assessed the mechanical stability, the surface characteristics and the histological response to implanted carbon by in vitro and in vivo studies, and have shown the superiority of a carbon pad implant over a simple drill hole of equal size in terms of fibrous response, collagen orientation and smooth surface covering (Minns, Muckle and Donkin 1982). Our own concern and that of other investigators regarding the fragmentation and synovial changes seen after carbon repair of ligaments (Rushton, Dandy and Naylor 1983; Thomas, Turner and Jones 1987) prompted this investigation.

Fig. 1

Rat patella six months after a carbon implant into the femoral condyle, showing some dark staining caused by fragmented carbon fibres.

MATERIALS AND METHODS

Implant. The carbon fibre pads consist of disc-shaped implants 3 mm thick and varying from 8 to 58 mm in diameter. The fibres used are made by heating polyacrylonitrile acid under pressure. These fibres, 6 to 9µm in diameter, are then fabricated into loosely-woven patches by conventional processes. The resultant implants are extremely pliable, soft and porous, containing 10% to 15% by volume of pure carbon fibre. A pad is inserted by drilling out a circle of articular cartilage, with penetration of the subchondral bone. The walls of the circle are cut

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Fig. 2

Section of synovium from a rabbit's knee, showing the minimal histiocytic and giant cell reaction to fragmented carbon fibres (Haematoxylin and eosin).

Fig. 3

Carbon fibre debris in the fibrous capsule and adjacent muscle, also showing minimal histiocytic reaction (Haematoxylin and eosin).

Fig. 4

Synovial tissue before carbon fibre implant, showing thickening and increased cellularity (Haematoxylin and eosin).

vertically with a pointed scalpel blade and the appropriate pad is inserted flush with the margins of the articular surface. No cement or special fixation is required, the pad becoming clotted into the defect within a few minutes of tourniquet release as a result of the carbon mesh ensnaring fibrin. A plaster back-slab is then used to hold the joint in extension for two weeks.

Animal studies. Eighteen adult male rats each had a carbon fibre implant 1 mm in diameter inserted loosely into a defect in the medial femoral condyle of the knee, so that it could possibly fragment into debris within days. After six months, the gross appearance of any fragmented tissue was noted and specimens of synovium, capsule, lymph nodes and articular cartilage were fixed and prepared for histology.

Sixteen adult New Zealand white rabbits had carbon fibre patches 3 mm in diameter implanted into the patella. Six months later, similar histological studies were carried out (Minns et al 1982). The patellae were also tested mechanically to assess the compliance of the resultant repair surface and compare it with normal articular cartilage.

Clinical studies. Forty-seven patients, average age 30 years (range 18 to 72) were assessed clinically and arthroscopically at an average of three years (range 2.5 to 5.5) after surgery. All had had carbon fibre pads implanted, 23 femorotibial and 24 patellar. The assessment was compared with the pre-operative state. Any synovitis, pigmentation or articular disruption were recorded. Implant fixation, surface alignment and the junction between the pad and hyaline articular cartilage were probed and biopsies were taken.

Histology. All pigmented tissue and synovial biopsy material from both animals and patients was prepared for sectioning by acrylic plastic embedding, because the softer paraffin-prepared material produced many artefacts due to the difficulty of cutting thin sections containing rigid carbon fibre. Sections at 5 and 10 µm thick were stained with haematoxylin and eosin, Van Gieson, Masson's Goldner and Weigert elastic stains. All sections were examined by a consultant histopathologist.

RESULTS

Three of 18 rat knees and 11 of 16 rabbit knees showed pigmentation with carbon fibre (Fig. 1), but histological examination of the synovium (Fig. 2) and the other related soft tissues (Fig. 3) showed only a minimal histiocytic and giant cell reaction.

In the 47 patients assessed pre-operatively grade III or grade IV synovial (Fig. 4) and articular changes were present in 46 cases (98%). On average, three years after surgery, 36 (77%) had an excellent or good clinical response with no synovitis and no particulate carbon fibre within the joint tissues, other than occasional fibres where the pad had rested against the opposite surface

during the period of immobilisation in plaster. Nine had mild general speckling but no gross or histological synovial reaction.

In two patients the pad had failed: hyaline cartilage suspensoids and carbon pigmentation were found in a 72-year-old woman (the oldest patient) who had a fracture of her implanted tibial plateau, and a 42-year-old man suffered progressive articular cartilage changes and required knee replacement. His biopsies showed only mild pigmentation (Fig. 5).

DISCUSSION

The results of both the experimental and clinical studies confirmed that the carbon pads had become filled with structurally strong fibrous tissue which is similar to that seen after arthroscopic abrasion arthroplasty (Johnson 1986). This tissue was predominantly type I collagen which further matured to type I and III collagen (Mendes et al 1988). Endochondral ossification was seen as an anchoring material in the deeper zones. The pads produced a smooth conforming surface continuous with the adjacent articular cartilage with restoration of apparently normal architecture. This may be related to improved compliance of the pad which protects the surrounding and underlying bone from dynamic loading. The frictional resistance of the resultant articular surface is much lower than that of fibrillated and degenerate articular cartilage; this provides reduced shearing during loading and less wear (Unsworth et al 1988). Crepitus was abolished in over 70% of patients after carbon pad implantation into the patella.

The animal studies showed that there was little synovial and soft tissue inflammation even after a deliberate attempt to pigment the tissues. In a study of failed carbon fibre reinforced polyethylene total knee replacement components, Wright et al (1988) found a foreign-body response only to the polyethylene material

Fig. 5

Section of the synovium from a knee containing a carbon fibre pad, showing some carbon fibre debris (Van Gieson).

and not to the carbon fibres. This is encouraging, and confirms the arthroscopic and arthrotomy findings in many of our cases during the last five years.

Our investigations have shown that woven carbon fibre pads may have a place in the treatment of osteochondral defects, giving a firm, dense and pliable structural cover with little or no synovial reaction. We are now studying the possibility of using these pads as a mode of storing harvested chondrocytes; this may produce an even firmer, more collagen type II compatible repair.

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