The histological appearance of carbon fibre implants and neo-ligament in man

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Summary

The results of this study indicate that a fibrous ingrowth occurs in man after surgical replacement of a tendon or ligament with carbon fibre. This ingrowth resembles normal tendon or ligament very closely, with parallel orientation of collagen fibres and fibroblasts. A multinucleate foreign-body giant-cell response was seen, but it was not possible to ascertain whether the fragmented carbon lay within or on these cells and other macrophagic components. Numerous intact carbon fibres were still present 2 and 3 years after implantation.

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Interest in the biological response to carbon has escalated in recent years, mainly owing to the apparent clinical success which has been achieved with carbon fibre implantation to replace damaged tendons and ligaments. This situation is almost unique in that a clinical procedure being performed routinely on humans has been accepted with a minimum of supporting biological research.

Although the use of carbon fibre as a potential implantable prosthetic device was described as early as 1969,[1] the implantation procedure for the carbon fibre ligament currently in use was introduced in the UK somewhat later.[2] Major advances have since been made at both the technical and the surgical level in South Africa.[3] The carbon fibre implant most commonly used in this country as well as overseas has been developed and manufactured by a South African plastics company. During July 1982 alone, 300 kits were supplied to local surgeons.

A number of reports have appeared on carbon fibre implantation in animals,[4-6] but no literature is available regarding histological responses after implantation in man. Nevertheless, carbon fibre implantation is being considered as the answer to a major clinical problem. The carbon itself is said to be fully biologically compatible, although some doubt has been expressed as to the suitability of this fibre in the repair of the anterior cruciate ligament in the knees of sportsmen.[7]

In this article we describe the histological appearance of three human tissue specimens after carbon fibre implantation, with the emphasis on the light microscopic findings.

Materials and methods

The ligament and tendons described in this article were removed from the knee and the hand respectively of a Black male and female who required replacement surgery. The knee implant was removed after 3 years, and two tendons from the hand were removed after 2 years. For the sake of simplicity the ligament and tendons will be collectively referred to as neo-ligaments in this article.

After surgical removal, the neo-ligaments were fixed in 10% formalin. The tissues were then dehydrated through a graded series of alcohols, embedded in wax and sectioned at 5 μm or 12 μm. Sections were stained with haematoxylin and eosin, haematoxylin and eosin plus aldehyde fuchsin for elastic tissue, a reticulum technique or the periodic acid-Schiff technique. Tissue from the same ligaments was digested with 1% crude bacterial α-amylase at 37°C for 2 hours to remove the ground substance and expose the collagen framework. It was then processed for scanning electron microscopy in the following way: the tissue was dehydrated through a graded series of ethyl alcohol immersions, dried using the critical-point technique and subsequently coated with a 200 Å thick gold coat in a Polaron sputter coater. The tissue was viewed with a Jeol T-20 scanning electron microscope.

Observations

The neo-ligaments were much thicker than the original carbon fibre implant and were covered by a thin shiny membrane. Histological examination of the carbon fibre implants showed that they had been fully infiltrated with well-orientated collagenous tissue. The collagen fibres and fibroblasts were in alignment with the carbon fibres and formed sheets of tissue between them (Fig. 1). Lifting of the carbon fibre out of the tissue occurred in the 5 μm sections. In the 12 μm sections the carbon fibres remained in position with the collagen orientated around them. The normal constituents of connective tissue such as collagen and fibroblasts were present, as well as small numbers of mast cells and numerous reticular fibres. There were no elastic fibres. In cross-section the collagen fibres surrounded and

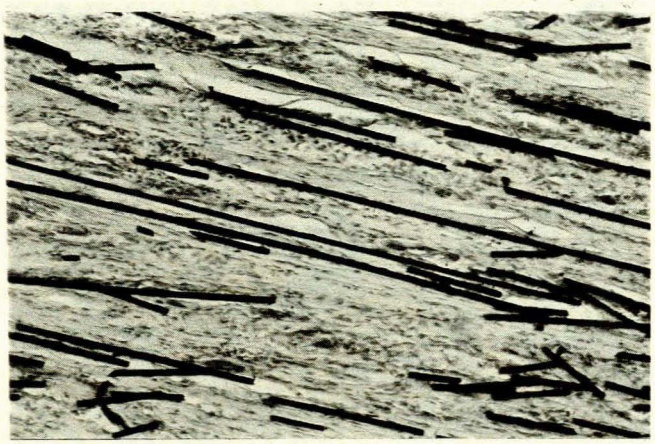

Fig. 1. Longitudinal section through a neo-ligament of the knee. Note the alignment of collagen fibres and fibroblasts between the carbon fibres (black). Banks of tissue occur between the widely spaced carbon fibres (H and E x 200).

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encompassed each carbon fibre (Fig. 2.). This was best depicted with the scanning electron microscope which showed numerous collagen fibres forming a palisade around the projecting carbon fibres (Figs 3 and 4).

Fragmentation of the carbon fibre had taken place (Fig. 5). Numerous foreign-body giant cells (multinucleate cells) were seen in relation to the carbon fibres (Fig. 6), particularly where the latter appeared fragmented. Ingested carbon appeared to be present in some of the foreign-body giant cells and in other cells possessing the characteristics of macrophages (Fig. 7).

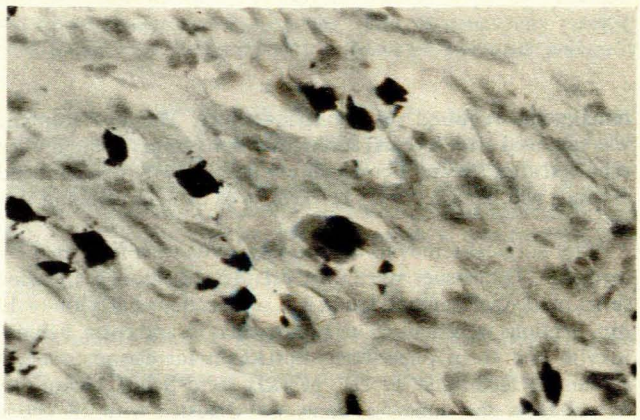

Fig. 2. Cross-section through a neo-ligament showing the collagen fibres surrounding each carbon fibre. Slight separation of the tissue from the carbon does occur during section (H and E x 400).

Fig. 3. Scanning electron micrograph of tissue digested with crude bacterial α-amylase. Note the carbon fibres projecting out of the collagen fibre network which surrounds them (x 3 000).

Fig. 4. Scanning electron micrograph showing the relationship between two carbon fibres and the surrounding collagen fibres in more detail (x 4 000).

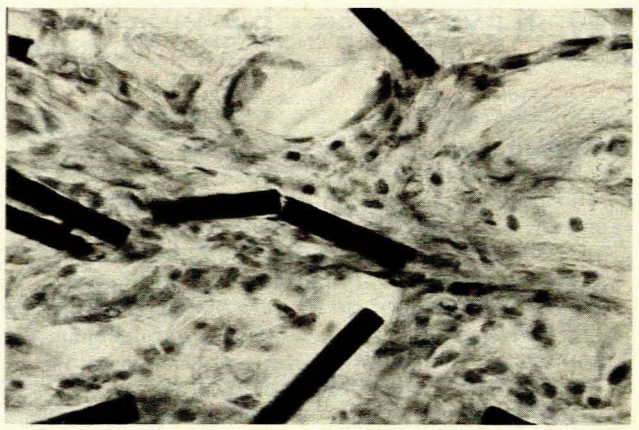

Fig. 5. Carbon fibre does fragment — as can be seen in this section of neo-ligament (H and E x 400).

Fig. 6. A foreign-body giant cell (FBG) is seen in this section of neo-ligament. It lies very close to the carbon fibre and appears to have ingested carbon particles (C) within it (H and E x 1 000).

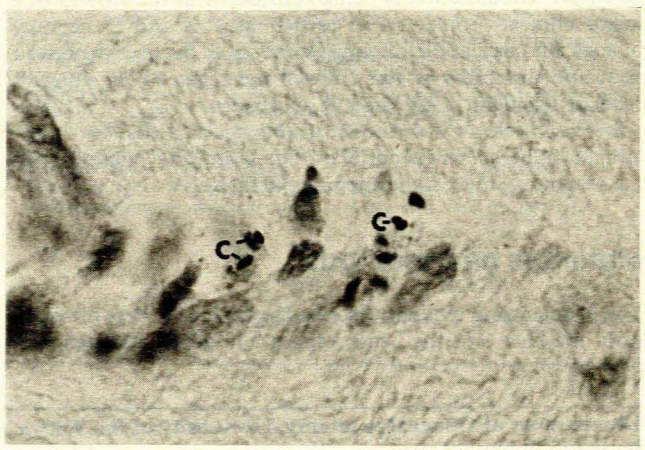

Fig. 7. Carbon particles (C) appeared to be situated within macrophage-type cells. The nature of the pigment makes it difficult to determine whether these particles occur within or on the cells (H and E x 800).

Examination of the proximal and distal ends of the carbon fibre implant in one tendon from the hand showed disorganized scar tissue within the matrix of the carbon. Blood vessels were present in all three ligaments.

Discussion

This study confirms in humans what other workers[4,8] have demonstrated in experimental animals, namely the ability of carbon fibre to act as a scaffold and in some way influence the formation of neo-ligament. This appears as an ingrowth of collagenous tissue into the carbon fibre, which results in an apparent increase in thickness of the original carbon fibre implant.

Although the presence of multinucleate cells has been reported by other workers,[4,6] their significance in this context is uncertain. Both groups of authors have described the presence of carbon particles in the multinucleate cells and in macrophages, and maintain that the carbon is transported away by these cells. It is very difficult to determine the exact location of exogenous pigments in a biological system, particularly with the light microscope, and it is therefore not possible to say whether the carbon was within or on the multinucleate cells in the present study. Unfortunately, regional lymph nodes were not available for examination.

Fragmentation of the carbon fibres was evident. However, it was impossible to determine whether this was due to some mechanical or chemical factor in the tissue and/or due to the sectioning of the tissue with a conventional steel microtome knife. Other workers[6] have encountered difficulties owing to lack of cohesion between the carbon fibres and tissue during sectioning. As the individual carbon fibres are 8 μm in diameter, a section at 12 μm was used in the present study. This permits the fibre to remain in position in the tissue and the orientation of the carbon to the collagen can be determined.

A large proportion of carbon fibre remained in the neo-ligament after 2 and 3 years, suggesting perhaps that the local carbon fibre is not as degradable as that used by workers in other countries.

An ingrowth of vessels into the neo-ligament from the adjacent vascular tissue occurred. Such an ingrowth is important in re-establishing a functional tendon.

Prosthetic replacement of ligaments continues to have great appeal when surgical repair has been unsuccessful. It is the view of many workers[9] that no material available at present can adequately fulfil the role of a *permanent* prosthetic implant. Although controversy surrounds the use of carbon fibre, this scaffold approach to replacement provides temporary mechanical integrity until the new ingrowth of tissue assumes mechanical function. However, as this study indicates, it is important to determine with precision the fate of the carbon, the efficiency of the new collagen, and the identification as well as the significance of the cellular components involved.

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