Part X
Medical applications

47

INTRODUCTION

Textile materials have always found medical uses, though usually in rather simple forms, such as bandages and dressings. More recently, some speciality textiles have come to be used in more demanding ways. According to Anand (1997), the medical uses of textiles can be categorised as follows:

- *non-implantable materials — wound dressings, bandages, plasters etc*
- *extracorporeal devices — artificial kidney, liver, lung etc*
- *implantable materials — sutures, vascular prostheses, artificial joints etc*
- *healthcare/hygiene products — bedding, clothing, operating room garments, wipes etc*

For disposable products, durability is of no concern and strength only has to reach minimum levels. Consequently the study of failure is not often required, though it may be needed when weak fibres, with some special properties such as wound healing, are used.

However devices and implants often need to operate for long periods subject to cyclic loading, whether due to the pumping of blood or the movements of joints. Here the study of damage and the lifetime before the product wears out are of great interest. Paradoxically, there are other situations where degradation after a certain time is desirable, because the body has grown new tissue to take over the function again.

There are a few relevant examples spread through the book. The polyester fibres in **8E(3)–(6)** were loaded with barium sulphate to make them opaque to X-rays for medical reasons. Damage to hair, as described in Chapter 19, may have medical as well as cosmetic implications. The overall fabric shown in **34G** was used in a virology laboratory. Toothbrush bristle was shown in **40H(3),(4)**. In addition, there is a link to biology through natural commercial fibres, cotton, wool and flax, which appear in many places in the book, and, more unusually, to thistledown and bacterial fibres in Chapter 21.

Because of the importance of the subject, a complete new Part has now been added. This starts with a detailed SEM examination of explanted textile ligaments from the knee and continues with some miscellaneous studies at UMIST and elsewhere.

48

FAILURE IN ANTERIOR CRUCIATE LIGAMENTS

Alan McLeod and William Cooke

Following considerable initial clinical success, the Surgicraft ABC ligament developed a pattern of performance where approximately 9% of the implanted prostheses developed signs of premature failure, i.e. a return to knee laxity or increased instability of the knee. A decision was then made to use the expertise available in UMIST to carry out SEM based fibre fracture analyses of the explanted remnants of failed ligaments, in the expectation that an understanding of the nature and cause of the break would lead to the development of a solution.

The anterior cruciate ligament (ACL) is one of the primary stabilising elements in the knee joint. The traumatic rupture of the ACL is a frequent sporting event resulting in knee laxity and episodes of the knee 'giving way'. The ABC prosthetic ligament has been in clinical use for the treatment of symptomatic deficiency of the ACL since 1985. The ABC ligament has twenty-four strands of a unit material comprising a partial polyester braid around a core that can be either polyester or carbon fibre. In order to be able to position the prosthesis in an anatomical position in the knee, it is implanted through a tibial drill hole, across the joint and up over the top of the lateral femoral condyle, **48A(1)**. Thirty ABC ligaments, which had ruptured in clinical use, were returned for mode of failure analysis. Of these eighteen had failed within the first year and eight had failed between two and four years post-operatively.

An explanted prosthesis, as received for examination, is shown in **48A(2)**. The analysis would start with a macroscopic examination with the object of identifying the point of rupture and relating that to the notes taken in the operating theatre when the ligament was explanted and the patient's history. Explanted ABC ligaments are covered by tissue ingrowth, **48A(3)**, which makes it impossible to examine the fracture morphology of the underlying polyester with an SEM. Therefore the tissue ingrown ABC ligaments were treated with a crude collagenase enzyme in an incubator; this breaks the bonds between the collagen cells allowing the tissue to be rinsed off exposing the artificial material, **48A(4)**. The entire tibial remnant and strands of unit material from the femoral remnant would then be mounted for SEM examination.

The ABC polyester ligament shown in **48A(2)** is a typical early failure, having ruptured spontaneously after only three months. This preliminary work established that the rupture was almost invariably located at the point where the prosthesis emerged from the tibial tunnel. The area of damage to the ligaments was extremely focussed. Within a few millimetres of the point of rupture, the artificial material was undamaged, **48A(5)**.

Another ABC polyester ligament, shown in **48A(6)**, failed six months after implantation. The macroscopic examination confirmed that rupture had occurred at the point where the ligament emerged from the tibial drill hole. After enzymatic cleaning, two distinct areas of damage were identified on the tibial remnant, **48A(7)**. Working from one side of the ligament, the point of rupture was at gradually increasing distances from the tibial end of the ligament up until the last three strands of ligament material which failed an additional 13 mm above the main rupture point.

In order to conduct a forensic mode of failure analysis, and so deduce the nature of the forces that cause rupture of prostheses, the investigation concentrated on the diverse modes of deformation, structural damage and breakage of the polyester filaments. Failures in the carbon fibres were uninformative, because, as shown later in **48E(3)**, they were always brittle tensile breaks. The pictures of polyester fibre damage in **48B–D**, which are categorised in the following sections, are a selection from the 30 explanted prostheses, and details of those which are illustrated are given in Table 48.1. In most cases, there was some peeling and fibrillation in addition to the main forms of damage.

CRUSHING, FLATTENING, SPLITS, FIBRILLATION

The SEM examination of the explanted material is of interest given the harshness of the situation from which the material has been taken. The prosthetic ligament, in an essentially aqueous environment at 37°C, is subjected to cyclic tensile loading varying from a negative load when the knee is flexed, to high peak loading in a sports engagement. Flexural and torsional cyclic loading is also present. High lateral loads can be present at the stress raiser created where the ligament emerges from the tibial drill hole.

The primary fracture morphology for any failure occurring within a year of implantation was flattening and crushing. A typical example is shown in **48B(1)**, where a flattened filament is looping over an undamaged filament.

In another, more unusual, example of a crushed filament, **48B(2)**, corrugations had been formed in the filament, which had been pressed against an intact bundle of polyester filaments.

Long axial splits, **48B(3)**, were frequently observed for early failures. Closer examination of the same filament revealed splitting and fibrillation within the main body of the filament, **48B(4)**. This internal splitting of a filament, **48B(5)**, creates points of weakness resulting in a fibrillated rupture **48B(6)**.

TENSILE FAILURE, SURFACE PEELING, TENSILE FATIGUE

Tensile breaks, **48C(1)**, were identified from material from six ligaments. However, tensile breaks were always a secondary fracture morphology. For example, with the ligament shown in **48A(7)**, the three projecting strands of material at one edge were found to have failed with tensile breaks as opposed to the remainder of the ligament, which failed with crushing and flattening. This pattern of fracture morphologies unambiguously demonstrated that rupture of the ligament was not the result of insufficient tensile strength for, if this was the case, the tensile breaks would have been present right across the ligament. Instead, failure was the result of focused mechanical damage working its way across the ligament until the last three strands were overloaded and failed with tensile breaks.

Some surface peeling, **48C(2)**, was identified to a greater or lesser degree in all the explanted prostheses. In general this is due to surface shear forces resulting from a lateral pressure on the prosthesis, although there is an indication that some surface peeling could result from adhesion between tissue ingrowth and the surface skin of the polyester filament, **48C(3)**. In an extreme form, the surface peeling can act layer by layer deeper into the filament, **48C(4)**. This layered surface peeling was noted at the level of the exit to the tibial drill hole for a prosthesis which had not ruptured but which had been explanted because of a reaction against wear debris released into the knee joint.

For two ligaments, a combination of a long surface peel ending in a tensile break, **48C(5),(6)**, was identified. This type of fracture morphology is associated with tensile fatigue (see **11C**). However, the surface peel could alternatively be the result of surface shear stresses and, if the ABC prosthetic ligament was subject to tensile fatigue, it is surprising that it could only be identified for two out of the thirty ligaments that were examined.

MULTIPLE SPLITTING FATIGUE, ROUNDED ENDS, KINK BANDS

For the group of ABC prosthetic ligaments which failed between two and four years after implantation, the fracture morphology identified to a greater or lesser degree on a majority of the implants was multiple splitting fatigue, **48D(1)**. The fatigue damage was not present throughout the ligament, but was isolated at the point of rupture. It has however, not been possible to establish whether or not the fatigue damage was the cause of the rupture or a result of the significant time lapse between the rupture and the explantation of the prosthesis. Both of the polyester filaments shown in **48D(1)** have fatigue damage with the more horizontal of the filaments having transverse splits indicating biaxial rotation compared to the more axially orientated splits of the other filament which indicates flexural fatigue.

The multiple splitting fatigue damage would often be present at multiple sites along individual filaments, **48D(2)**, culminating in either the characteristic brush ends seen in **48D(2)**, where the filaments have failed at fatigue damage sites, or in rounded ends, **48D(3)**, where further abrasive wear has occurred. In this example it is still possible to identify the cracks on the rounded end corresponding to the multiple splits of the original fatigue damage.

Multiple splitting fatigue was also identified in association with kink bands such as shown in **48D(4)**. The cracks of the multiple splitting fatigue can clearly be seen to start from a kink band split, **48D(5)**, and then follow a line of weakness from one line of kink bands to the next, changing direction slightly at each band. Kink bands were also identified on their own as developing bands and as bands opening into cracks, **48D(6)**.

Table 48.1 — Details of prostheses

Code **Plates**	Months *In vivo*	Location of failure of strands; main failure modes; other notes
EARLY FAILURES		
RI **A(2); E(3)**	3	most at ETDH; two pulled free of femoral remnant; C&F; spontaneous failure
TE **A(3),(4); B(3),(4)**	5	most at ETDH; rest about 10 mm back; C&F; ingrowth in patches
BO **A(6),(7); C(1)**	6	most at ETDH; 3 were tensile breaks, 13 mm above main rupture; C&F
HM **E(7)**	7	70 mm away from tibia, over lateral femoral condyle, where shielded from load, so no clinical reason for failure; sharp cut made during explant; no other damage; little tissue ingrowth; no information on why removed (may be clinical synovitis)
BB **C(4)**	8	removed due to adverse synovial reaction; mostly undamaged; some damage at ETDH; SP
DF **B(2)**	10	ragged over length of 12 mm; various; damage filaments away from point of break; return to instability after 2 months due to failure of prosthesis; removed 8 months later
TA (c/p) **E(6)**	10	C&F with fibrillation; heavy tissue ingrowth
BE **D(6)**	12	most at ETDH; 4 were 25 mm away at exit of femoral drill hole, used in operation in an attempt at isometric positioning; some strands failed at both locations; MS
HA **C(5),(6)**	20	ETDH; apparently tensile fatigue; no crushing or multiple splitting
RO(c/p) **B(1)**	20	only femoral remnant held together by tissue available; C&F; some MS&SP
LATE FAILURES		
SI (c/p) **C(2),(3); E(5)**	32	ETBD; heavily fragmented; MS and rounding; may be some high-speed breaks; rugby player's prosthesis, lasted 2 seasons, then broken after 27 months in heavy tackle; between failure and explant, tissue had formed a mat at femoral end
JO **D(1)**	33	prosthesis fragmented when received; much tissue growth; probably ETDH; tangled filaments with MS: crushing at femoral end probably occurred at removal of bollard
LE **D(3)**	35	ETDH; MS and rounding plus tensile breaks at femoral end
DI **D(4),(5); E(1,2)**	39	most at ETDH; MS&SP; no crushing; spontaneous failure
LA **D(2)**	39	most at ETDH, with MS; some projecting, 5 mm (1), 9 mm (2), 21 mm (1), tensile breaks

(ETDH is exit of tibial drill hole; C&F is crushing and flattening; MS is multiple splitting; SP is surface peeling; c/p is carbon/polyester)

INTACT FIBRES, CARBON FIBRE, TISSUE INGROWTH, CUT FILAMENTS

Away from the point of rupture, there is occasional evidence of surface peeling from inter-filament abrasion but the vast majority of the artificial material is undamaged. The undamaged polyester, **48E(1)**, and carbon fibre, **48E(2)**, are from the intra-articular portion of a prosthesis that was implanted for thirty-nine months.

The carbon fibres used as the core element in some of the examined prostheses always failed with a brittle tensile break, **48E(3)**, at the point of rupture of the ligament. This repetitive brittle fracture, irrespective of the nature of the force that caused the rupture of the prosthesis, effectively excluded the carbon fibres from the mode of failure analysis. However, the carbon fibre was examined for any evidence of the fragmentation that has frequently been associated with implanted carbon fibre. No evidence was identified of fragmentation away from the point of rupture of the ligament, but there was considerable evidence of tissue ingrowth adhering to the carbon fibres, **48E(4)**.

The tissue ingrowth is more than just a surface covering; it penetrates first between the strands of unit material and then between the filaments of the polyester and carbon yarns. The ingrowth is illustrated in **48E(5)**, which is a cross-sectional view through the middle section of an ABC ligament which was ruptured in a fall 10 months after implantation. The core bundles of carbon fibre can clearly be seen; surrounding each core is the lighter polyester forming the partial braid. Filling the spaces between individual strands and individual filaments is the new tissue ingrowth.

An unexpected bonus of the SEM examination of the explanted polyester was the evidence of oriented tissue ingrowth, such as shown in **48E(6)**, in which a network of collagen fibres runs along the polyester filament. The ligament had been implanted for thirty-two months. The braided structure of the ABC prosthesis results in the polyester following the longitudinal axis of the ligament. The orientation of the collagen along the polyester indicates that the collagen will also be oriented along the longitudinal axis of the ligament.

The fracture morphology analysis was also able to identify damage that was unrelated to the rupture of the prosthesis. In particular an instance of the polyester having been cut with a scalpel, **48E(7)**, was identified. It is assumed that the cut was made during the explantation operation. The breaks are flat but unlike standard tensile breaks, they are at varying angles and are smeared into each other by the passage of the scalpel blade.

PATTERNS OF FAILURE

It was concluded from the SEM studies that early failures, within one year, resulted from crushing at the point where the prosthesis emerges from the exit to the tibial drill hole. Late failures, after two to four years, occurred at the same location, but the primary fracture morphology was multiple splitting fatigue, which is due to bending and twisting, though crushing was also found in some late failures.

There were some variations from this pattern of division into early and late failures, with failures, which occurred after more than two years having morphological features found in early failures. For example, in one carbon/polyester ABC prosthesis, an exact duplicate of the twisting football injury took place 28 months post-operatively. The rupture of the reconstructed ACL was clinically indistinguishable from the rupture of a natural ACL, with a full haematoma and pain. Examination of the ligament showed extensive tissue ingrowth, but also evidence that there had been widespread damage and failure of strands a considerable time before the final rupture of the reconstructed ACL. In particular, there was an increase in bulk of the carbon core, which would not have been possible if the polyester braid had been intact.

The mode of failure analysis of explanted prosthetic ligaments identified the point of rupture and the mechanical nature of the forces causing the ruptures. Working with clinical Research Fellows, a link was established between the mechanical damage and the impingement of the ligament resulting from a misplacement of the tibial drill hole. This led directly to the development of new instrumentation to objectively position and prepare the tibial drill hole. This has virtually eliminated the early failure of ABC ligaments.

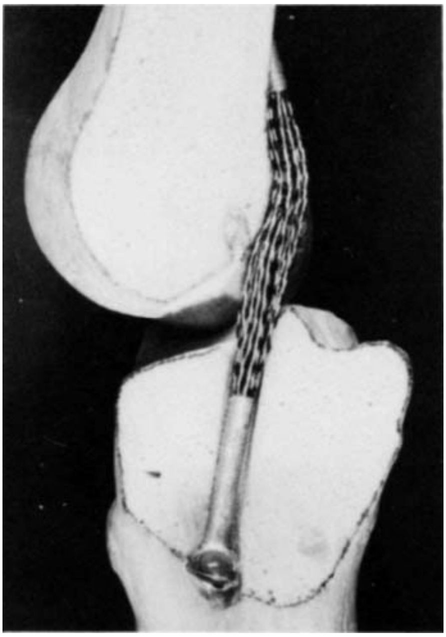
STUDIES OF OTHER PROSTHESES

In addition to studies of ABC ligaments, a few other prostheses have been examined. The Leeds-Keio ligament is an open weave polyester tube, which is intended to act as a scaffold for new tissue ingrowth. Two ligaments were examined, one of which had been explanted within a year post-operatively and one after about two years. In the early failure, which had little tissue ingrowth, a substantial amount of the polyester had become detached, and the fibres showed crushing damage and some splitting and attenuation. The late failure was heavily ingrown by new tissue, which may have interfered with load sharing between the polyester strands, and the damage consisted of multiple splitting fatigue, including long axial splits and attenuation of fibres.

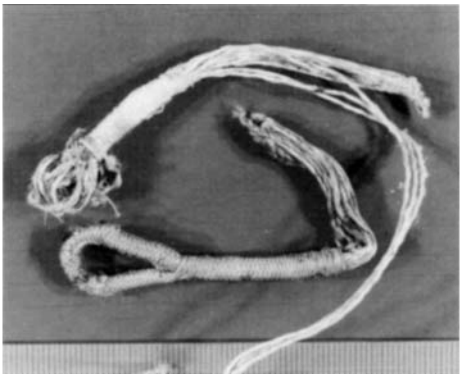
The Kennedy Ligament Augmentation Device (LAD) consists of nine strands of braided polypropylene and is used to augment autologous grafts. In one procedure, the surgeon routinely removes the LAD after 12 to 18 months, in order to avoid potential long-term problems due to artificial material in the knee. We examined a Kennedy LAD which had been used to augment a bone-patellar tendon-bone autologous graft. The LAD had been passed through a tibial drill hole and over the top of the lateral femoral condyle. After explantation, it was found to have ruptured at the exit to the tibial drill hole. There was no tissue ingrowth. SEM examination showed that the primary fracture morphologies of the polypropylene fibres were long axial splitting, fibrillation and multiple splitting fatigue, **48E(8)**. There was no sign of crushing. Although conclusions cannot be firmly drawn from one study, this does suggest that polypropylene is less fatigue resistant than polyester, which would explain the clinical reports of no statistically significant differences between augmented and non-augmented grafts.

The Graf Spinal Ligament System is an alternative to traditional metalwork prostheses. Two titanium pedical screws are linked by a band consisting of a flat braided polyester tube sewn together to make a ring. The primary advantage of the flexible system is that the surgery is less destructive, leads to earlier recovery and can be offered at an earlier stage of a degenerative condition. In bands removed from a patient after several months, there was little tissue attachment, due to the tightness of the braid. There were areas of damage on the insides of the bands and some strands had failed completely. The fracture morphology of filaments was that of crushing and flattening, with no evidence of splitting or fibrillation. The damage could be avoided if the band were positioned to avoid contact between the overlapped section of braid and the bone screw.

Investigations of this sort are both time-consuming, in the painstaking dissection and examination of explanted prostheses, and require good collaboration with the medical team in order to maximise the information available. When this is done, the mechanisms of failure can be identified, and this, in turn, leads to ways of improving the choice and construction of material and the details of the surgical procedures.

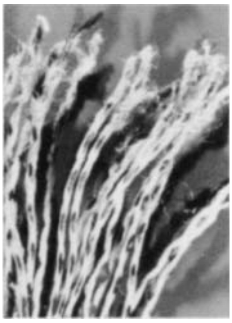


1

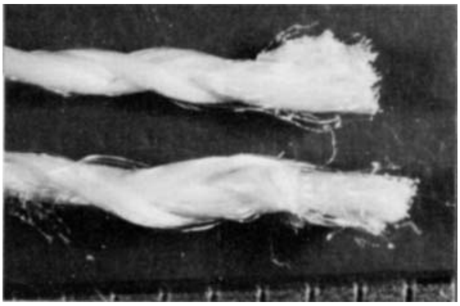


2

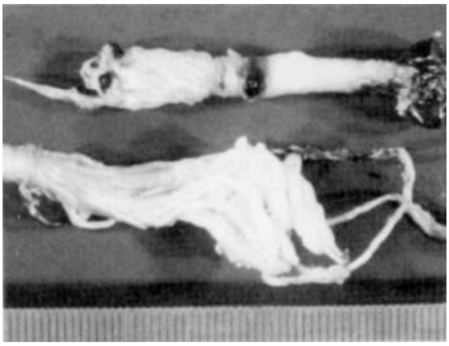
3



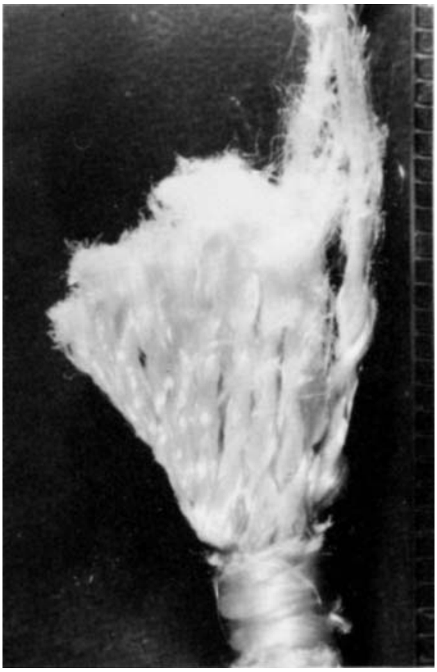
4



5

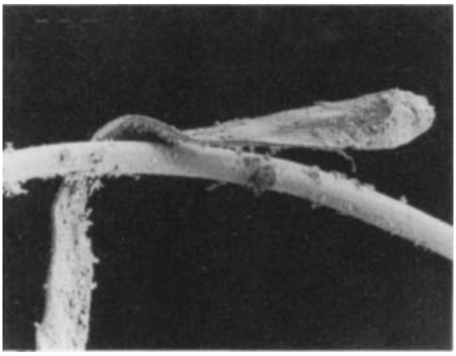


6

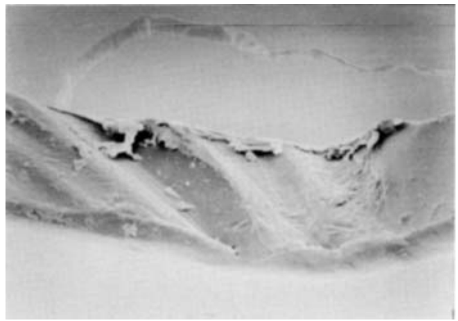


7

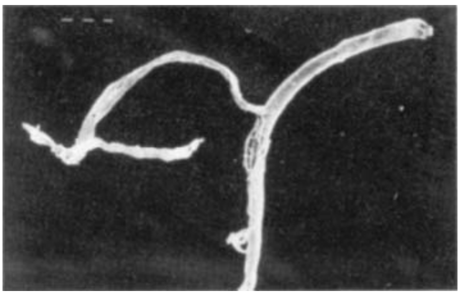
Plate 48A — ABC anterior cruciate ligament (ACL).
(1) The route taken by the ABC prosthetic ACL. (2) Prosthesis as received for examination: RI. (3) Prosthesis before cleaning: TE. (4) Prosthesis after cleaning: TE. (5) Localisation of damage: RI. (6) Tibial remnant of another prosthesis as received: BO. (7) Cleaned portion of prosthesis: BO.



1

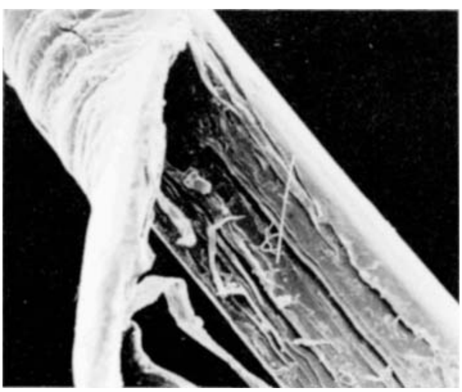


2



3

4



5

6

Plate 48B — Filaments from explanted ABC ligaments.
(1) Flattened filaments: RO. (2) Crushed filament: DF. (3),(4) Filament with an axial split at low and high magnification: TE. (5),(6) Internal splitting and fibrillation in a filament from another ligament.

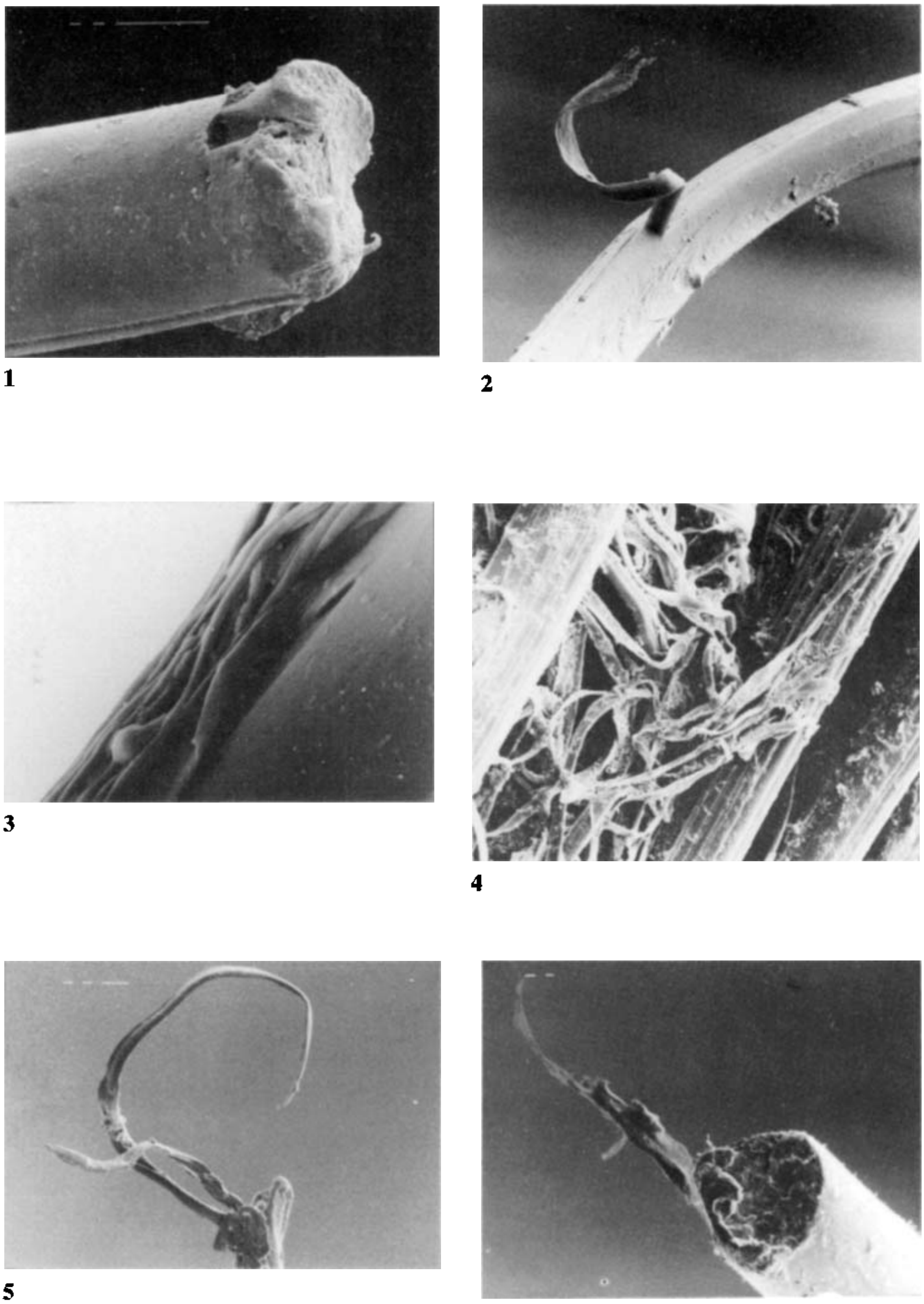
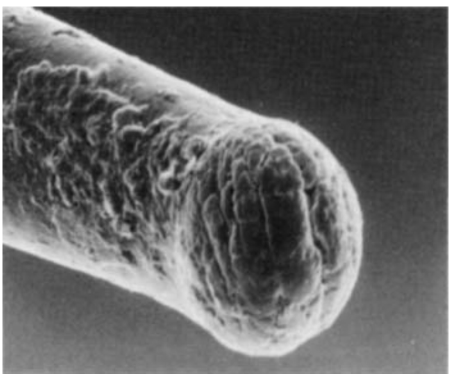


Plate 48C — Filaments from explanted ABC ligaments (continued).
(1) Tensile break: BO. (2) Surface peeling: SI. (3) Tissue adhesion with possible peeling: SI. (4) Layered surface peeling: BB. (5),(6) Possible tensile fatigue: HA.

1

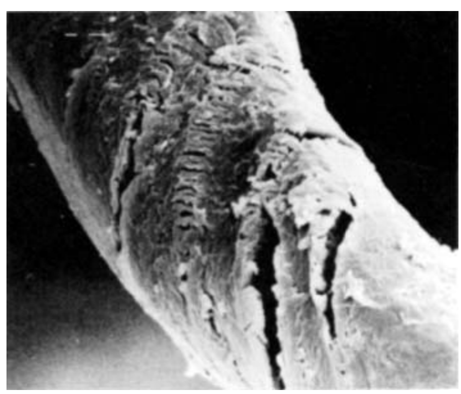
2



3

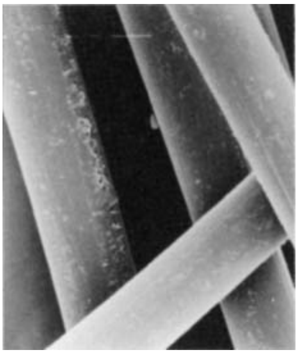
4

5



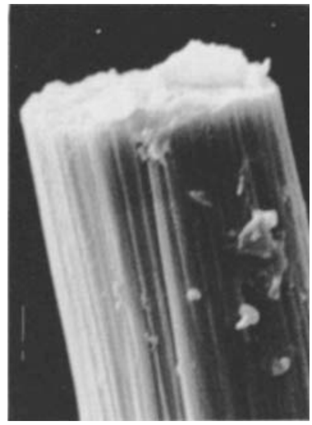
6

Plate 48D — Filaments from explanted ABC ligaments (continued).
(1) Multiple splitting: JO. (2) Multiple splitting and resulting breaks: LA. (3) Rounded end: LE. (4),(5) Kink bands combined with multiple splitting: DI. (6) Kink bands opening into cracks: BE.



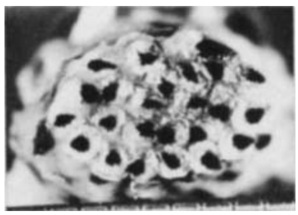
1

2



3

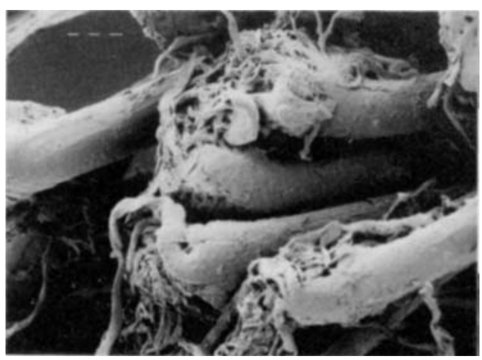
4



5

6

7



8

Plate 48E — Filaments from explanted ABC ligaments (continued).
(1) Hardly damaged polyester filaments from the intra-articular region away from the point of break: DI. (2) Undamaged carbon fibres from the same region: DI. (3) Carbon fibre break.
Tissue ingrowth in ABC ligament.
(4) Tissue adhering to carbon fibres. (5) Tissue ingrowth within the prosthesis: SI. (6) Tissue ingrowth along the surface of polyester fibre: TA.
Other damage in ABC ligament.
(7) Polyester filaments cut by scalpel: HM.
Failed Kennedy LAD prosthesis
(8) Fibrillation of polypropylene fibres.

49

DRESSINGS AND IMPLANTS USING SPECIAL FIBRES

In addition to the use of regular commercial textile fibres in a variety of medical applications, special fibres with particular properties have also been developed. These may promote healing or be subject to biological degradation when only temporary inclusion within the body is needed.

A cut through a Kaltostat haemostatic wound dressing, composed of calcium alginate fibres, is shown in **49A(1)**, with the appearance of a cut fibre in **49A(2)**. A hole in such a dressing is seen in **49A(3)**. The fibre ends have rather irregular breaks, **49A(4)–(6)**, which indicate a mixture of shear splitting and tensile rupture. One example, **49A(7),(8)**, appears to be a tensile fatigue break, similar to those in Chapter 11.

Elizabeth Norton of the University of Cambridge has provided information and SEM pictures on studies of poly(glycolic acid) fibres. This material and its copolymers are semi-crystalline polymers which degrade by a hydrolytic mechanism. They are biodegradable and biocompatible allowing them to be used in biomedical applications ranging from resorbable sutures to controlled drug release devices. The exact morphology of these materials and the fundamental process of degradation is currently uncertain, Cohn *et al* (1987), but by gaining a better understanding of the mechanism of biodegradation it is hoped to develop new improved medical materials. Biodegradation of the surgical suture material, Maxon, which is a copolymer of poly(glycolic acid) and poly(trimethylene carbonate) described by Metz *et al* (1990), can be modelled using an *in vitro* system consisting of a buffered solution to maintain the physiological pH of 7.4, Reed and Golding (1981).

Undegraded Maxon has a very smooth, undamaged surface, **49B(1)**, but between 28 and 35 days of exposure to the solution long cracks begin to form in the direction of the fibre axis, **49B(2)**. On further hydrolytic attack circumferential cracking occurs, dramatically increasing with degradation time, **49B(3),(4)**. The material has then become weak and brittle fractures, as seen in **49B(5)**, can occur. The surface layer, which is rich in poly(trimethylene carbonate) can also flake off by a brittle fracture, exposing the interior, **49B(6)**.

In order to determine the effect of drying on the surface morphology of Maxon, environmental scanning electron microscopy (ESEM) was used. This technique allows wet samples to be studied, thus avoiding harsh sample preparation such as coating or drying. A degraded sample of Maxon was placed in the ESEM and slowly dried by increasing both the temperature and the vacuum. Initially, the sample appeared almost smooth with only a few longitudinal cracks. More severe cracking was seen to happen very rapidly on drying. The result depended on the rate of water removal, and **49C(1),(2)** show two pieces of the same material dried under different conditions.

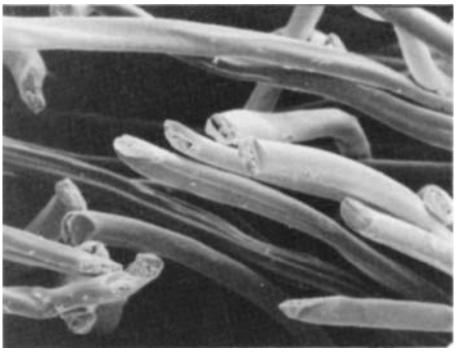
This study shows that there is a major change to the surface morphology of biodegradable polymers on degradation, but the appearance is greatly affected by the techniques, such as harsh drying, used in SEM studies. The ESEM experiment indicates that there will be large differences between *in vivo* and *in vitro* conditions.

Although conventional metal plates and screws are beneficial in the early stages of fracture healing, they can cause long-term problems. This has led to research on biodegradable polymers for fracture fixation. Choueka *et al* (1995) have carried out a study of the degradation of glass fibres designed to be used as reinforcement in a composite with tyrosine-based polymers.

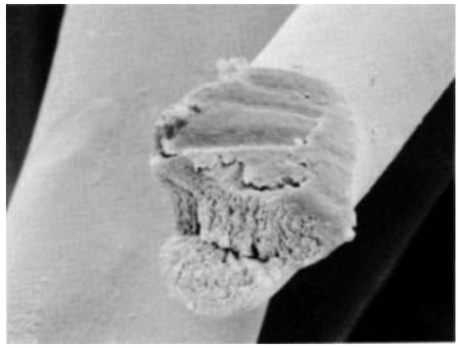
The fibres had a composition of 54% PO_4, 27% Ca, 12% ZnO, 4.5% Fe_2O_3, 2.5% $NaPO_3$, and were drawn from the melt by standard techniques of glass fibre formation. In order to study the effect of annealing, the fibres were tested in three forms: reheated to 420°C;

reheated to 250°C; and as first made. Chemical degradation was performed in tris-buffered HCl solution and chemically monitored. Tests were also performed in calf serum and in simulated body fluid. The fibres as made have a smooth, clean surface and showed almost no change in appearance for the first 60 days exposure to the physiologic solutions. Then, between 60 and 90 days, the fibres developed cracks and peeling away of a thin outer shell, **49C(3)**, but maintaining the overall structure of the fibre. All three forms behaved in a similar way.

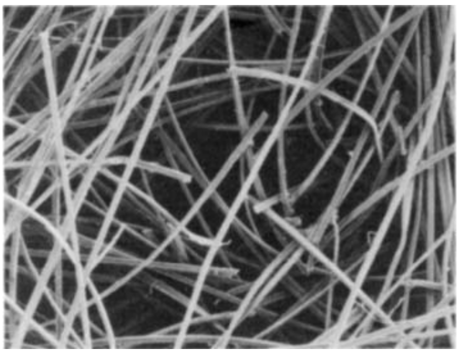
In the tris-buffered HCl, the degradation was much more rapid and there was a marked difference in the modes of degradation. Those that were not annealed or were treated at 250°C delaminated in a way that destroyed the overall integrity of the fibre, **49C(4)**. This is particularly clearly seen in the cross-section in the middle of **49C(5)**. Fibres treated at 420°C developed craters on the surface, **49C(6)**, but the fibre remained intact.



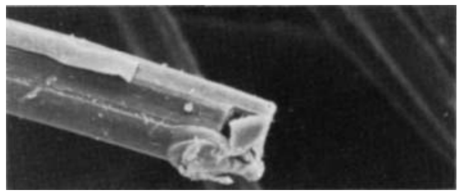
1



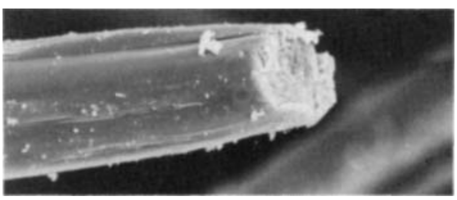
2



3

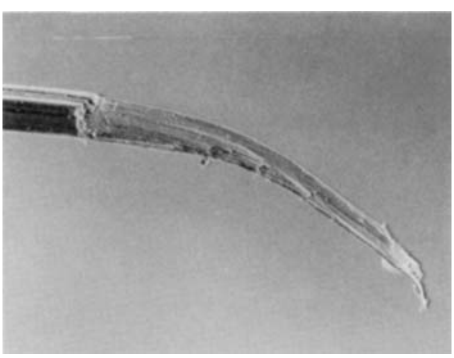


4

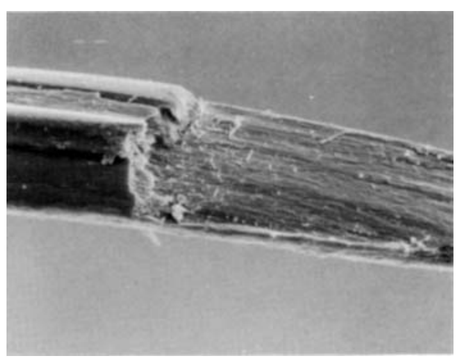


5

6

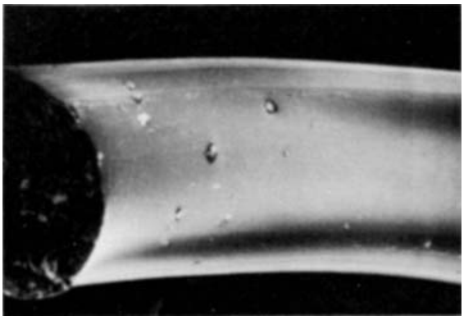


7

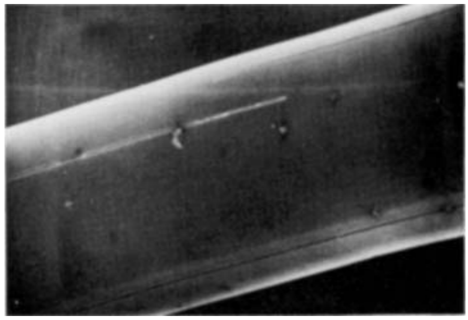


8

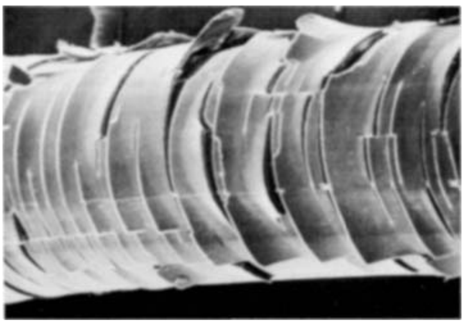
Plate 49A — Calcium alginate fibre wound dressing.
(1) Cut portion. (2) Cut fibre. (3) Hole in dressing. (4)–(6) Broken fibres from hole. (7),(8) Apparent tensile fatigue failure.



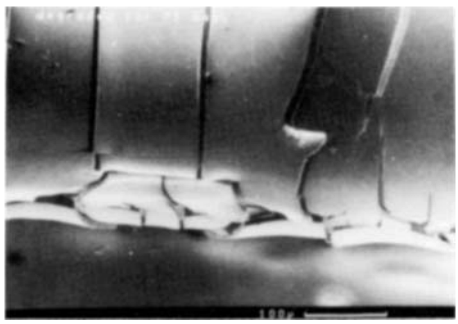
1



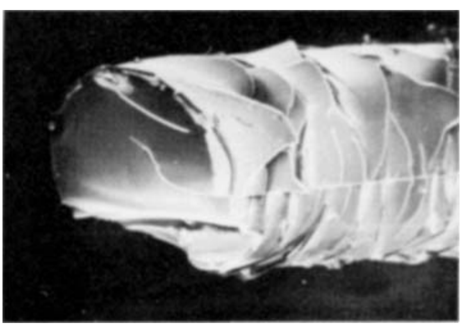
2



3



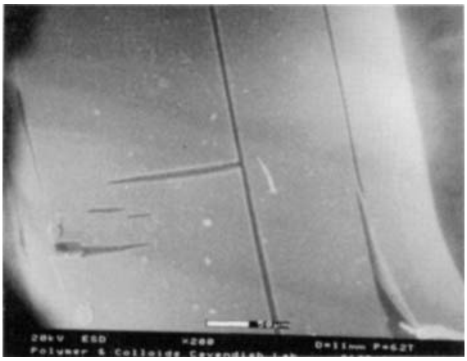
4



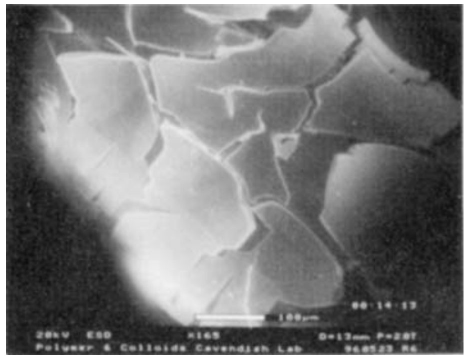
5

6

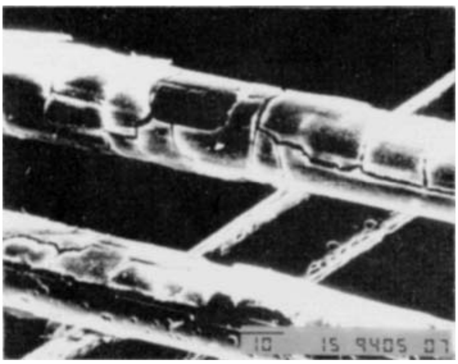
Plate 49B — Studies of Maxon suture subject to hydrolytic degradation, courtesy of Elizabeth Norton, University of Cambridge.
(1) Fibre as received; on the left is the end of the suture. (2) After about 30 days. (3)–(6) After 73 days.



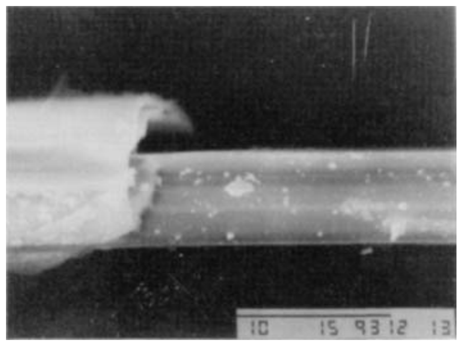
1



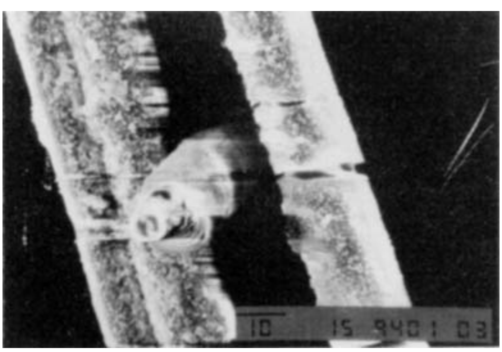
2



3



4



5

6

Plate 49C — Studies of Maxon suture subject to hydrolytic degradation, courtesy of Elizabeth Norton, University of Cambridge (continued).

(1),(2) Two samples dried under different conditions in an environmental SEM.

Degradation of calcium phosphate fibres used in absorbable implants, courtesy of Jose Charvet, Hospital for Joint Diseases Orthopaedic Institute, New York.

(3) Heat-treated fibres after 90 days in calf serum.

After 2 days in tris-buffered HCl.

(4) Non-heat-treated fibre. (5) Axial and cross-sectional views of non-heat-treated fibres. (6) Fibre annealed at 420°C.