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Carbon and polyester fibers as a scaffold for bone repair

Studies of segmentary implants in the rabbit radius

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To determine the function in the repair of bone defects, implants of carbon and polyester fibers of comparable dimensions were used to replace a 2-cm long segment of the radius of 29 rabbits. The healing process was analyzed by scintigraphic, radiographic, and histologic methods after periods of 15–90 days, comparing the results with a control group without implants.

In the rabbit, carbon and polyester fibers did not induce repair of bone defects, although they did permit invasion of the implant during the later stages.

Since Jenkins et al. (1977) reported that carbon fibers could induce the formation of tendons, this kind of implant has been employed in different experimental and clinical situations. Histologically, bone growth was observed between the carbon fibers at the anchorage zones of such ligaments (Alexander et al. 1981, Claes and Neugebauer 1985, and Weiss et al. 1985). Minns et al. (1982) also found that repair of osteochondral defects was improved structurally and mechanically by carbon fiber implantation.

The neotendon induced by polyester fibers seems to be of better quality than that induced by carbon fibers (Amis et al. 1984).

We have studied the effect of fiber implants in the repair of bone defects.

Materials and methods

Twenty-nine adolescent New Zealand white rabbits of both sexes (average weight 2.4 kg) received 2-cm implants of carbon fibers (Thornel 300 wyp 15/10, Union Carbide) and polyester fibers (5/0 Dacron 18", Alcon Iberhis).

Under anesthesia, both radii were surgically exposed on their anterior face. After separating the periosteum, a 2-cm cylindric fragment was removed from the middle third of the bone with an electric saw. The implants were anchored to the bone with a coated, braided polyglactin suture (4/0 Vicril) that was passed through holes drilled in the anterior cortex of the radius (Figure 1). The wound was closed in planes, and both limbs were bandaged with cushioned plaster of Paris and joined to each other at the back. After the operation, the animals were allowed to move around at will. In an initial experiment us-

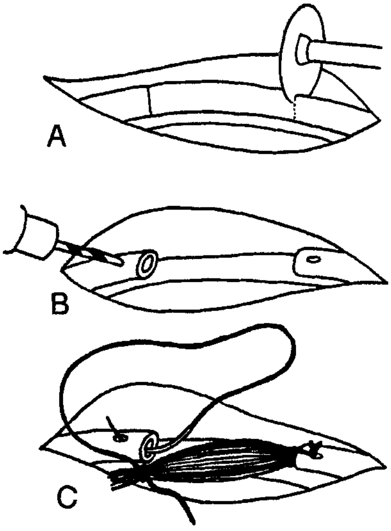

Figure 1. The operation: A. Transverse radial osteotomies. B. Holes drilled on the anterior cortex of the radius. C. Anchorage of the implant with a suture.

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Table 1. Radiographic findings

Group	Time (days)	Procedure	n	Length of ossification (part of defect)						Bridge of bone (thickness as part of defect) (n)	
				Proximal (n)			Distal (n)				
				1/3	2/3	3/3	1/3	2/3	3/3	1/3	2/3
I	15	1	5	3	–	2	3	1	1	–	–
I	15	2	5	3	1	1	2	2	1	–	–
I	30	1	6	1	3	2	2	2	2	–	–
I	30	2	6	1	4	1	2	3	1	–	–
I	60	1	6	–	1	–	–	–	1	3	2
I	60	2	6	–	–	–	–	–	–	3	2
I	90	1	6	–	–	–	–	–	–	3	3
I	90	2	6	–	–	–	–	–	–	2	4
II	90	1	6	–	–	–	–	–	–	3	3
II	90	3	6	–	–	–	–	–	–	3	3

Group: I carbon implant/bony defect control, II carbon implant/polyester implant.
Procedure: 1 carbon, 2 bony defect, 3 polyester.

ing 23 rabbits, a carbon implant was placed on the right side, leaving the left side empty. The animals were killed at 15–90 days in groups of 5 or 6. In a second experiment using 6 rabbits, a carbon fiber was placed on the right side and a polyester fiber on the left; these animals were killed after 90 days.

Scintigraphy. The 90-day animals were studied scintigraphically at 15, 30, 60, and 90 days after surgery. One mCi of ^{99m}Tc-MDP was injected 2 h before recording in an Actichamber 3400. A quantitative analysis of areas of interest was carried out. Using an electronic pencil, the computer screen showed three points that corresponded to the zones of proximal and distal resection of the bone, and one zone equidistant from the other two. These zones gave an approximate idea of the activity occurring at the ends and center of the defect, except that the activity of the ulna interfered. The scintigraphs were recorded on a MAFE 100 NIF film. The results were compared with recordings from the central zone of the humerus.

Radiography. All the pieces underwent profile x-ray exposure on a 200 CGR sinograph (focus 0.1 mm, 35 Kv and automatic mAs) using Kodak Min-R film. To study the radiographic findings, we took into account the degree of bone growth observable at lengths of 1/3, 2/3, or 3/3, both on the proximal and the distal half of the defect. Where bridges of bone had grown, these were evaluated according to whether they occupied 1/3, 2/3, or all of the width of the defect.

Histology. The specimens were fixed in 10 percent formaldehyde, decalcified in 10 percent nitric acid, embedded in paraffin, stained with hematoxylin-eosin, Masson trichrome, and the Wilder silver impregnation technique, and observed in a Zeiss microscope. To evaluate the results in each animal, the degree of bone growth in the defect, bone invasion in the implants, and the presence of bone marrow were studied.

Results

Radiographic findings (Table 1)

The defect was repaired gradually, with no important differences among the three procedures carried out. After 60 days, an interesting finding was that in almost all the cases a bridge of bone had grown between the osteotomized extremes (Figure 2).

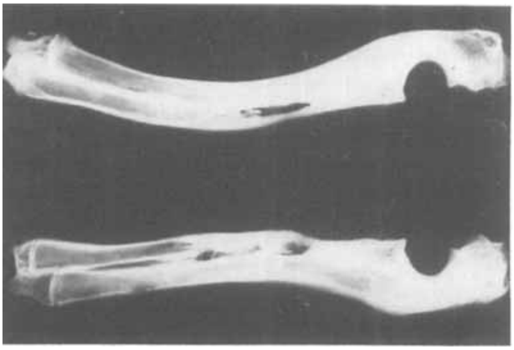

Figure 2. The degree of defect repair at 90 days: upper sample (polyester implant), supported by the periosteum and ulna, and lower sample (carbon implant), supported by periosteum.

Table 2. Histologic findings

Group	Time (days)	Procedure	n	Failed implant (n)	Bone ingrowth into the defect (n)						Thickness of bone ingrowth into implant (n)		Bone marrow amount (n)		
					a	b	c	d	e	f	1/3	2/3	a	b	c
I	15	1	5	–	2	3		–	–	–	–	–	–	–	–
I	15	2	5	–	1	4	–	–	–	–	–	–	–	–	–
I	30	1	6	3	1	2	2	1	–	–	–	–	–	–	–
I	30	2	6	–	–	1	3	2	–	–	–	–	–	–	–
I	60	1	6	–	–	–	1	4	1	–	5	–	1	–	–
I	60	2	6	–	–	–	–	2	3	–	–	–	3	–	–
I	90	1	6	–	–	–	–	3	3	–	1	5	2	–	–
I	90	2	6	–	–	–	–	1	2	3	–	–	–	2	3
II	90	1	6	–	–	–	–	2	4	–	–	6	2	–	–
II	90	3	6	–	–	–	–	2	4	–	1	5	2	–	–

Group: I carbon implant/bony defect control. II carbon implant/polyester implant.
Procedure: 1 carbon, 2 bony defect, 3 polyester.
Bone ingrowth into the defect: a small amount, b moderate amount, c large amount, d bridge of bone 1/3 of thickness of defect, e bridge of bone 2/3 of thickness of defect, f complete bridge of bone.
Bone marrow amount: a small, b moderate, c large.

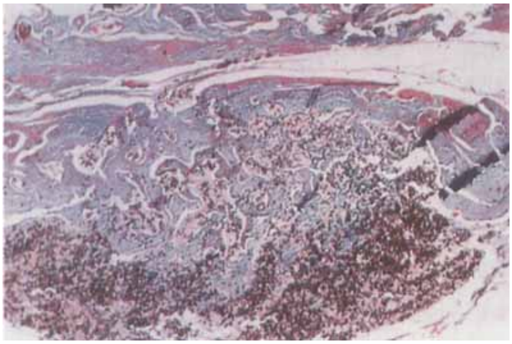

Figure 3. Transverse histologic section of the carbon-fibre implant at 90 days showing an important degree of invasion of the bone tissue. HE, x40.

Histologic findings (Table 2)

15 days. The defect was occupied by a highly vascularized fibrous tissue with osteocartilaginous zones on the osteotomized extremes and in contact with the ulna. Transverse sections of the specimens with implants revealed a thick fibrous barrier isolating the carbon fibers from bone growth.

30 days. The repair callus was more developed, in some animals appearing as a bridge of bone. Three of the cases with carbon-fiber implants showed a rejection reaction with necrotic tissue. Despite this, bone growth was observed near the ulna. In the other 3 cases that did not show rejection, the fibrous tissue surrounding the implant was narrowed, and one of the animals showed an incipient bridge of bone.

60 days. Whereas the defects of the control animals were almost completely occupied by bone, those treated with carbon-fiber implants did not exhibit a very important bone-tissue component. Transverse sections revealed that the lining of fibrous tissue had disappeared and that bone tissue had begun to invade the implant. The appearance of bone marrow was also observed in this period.

90 days. In the controls an increase in the maturity status of the bone together with the presence of higher proportions of marrow were observed. In the animals receiving implants, invasion of the bone was more pronounced (Figure 3). Although repair with the two implants was similar, penetration into the osteoid among the fibers of the polyester filament was not seen.

Scintigraphic findings (Table 3)

The Manova multivariate test showed no significant differences between the carbon, carbon polyester, and control bones.

Discussion

The radiographic findings yielded morphologic information concerning bone repair. Like Baadsgaard (1970) and Wittbjer et al. (1982), we observed the presence of radiocubital synostosis. This was probably a process of reactive osseous formation and

Table 3. Scintigraphic findings. Mean *SD*

Group	No.	Time (days)	Proximal region				Central region				Distal region			
			Right		Left		Right		Left		Right		Left	
I	6	15	3.68	*0.72*	4.14	*1.52*	1.92	*0.32*	1.72	*0.56*	2.67	*0.47*	2.27	*0.34*
I	6	30	3.20	*0.70*	2.30	*0.51*	2.22	*0.84*	1.52	*0.30*	3.41	*1.14*	2.35	*0.68*
I	6	60	1.84	*0.20*	2.21	*0.94*	1.42	*0.13*	1.32	*0.38*	1.39	*0.21*	1.52	*0.18*
I	6	90	1.58	*0.23*	2.39	*0.84*	1.05	*0.20*	1.30	*0.34*	1.29	*0.31*	1.35	*0.31*
II	6	15	3.32	*0.40*	3.61	*1.06*	1.66	*0.25*	1.91	*0.62*	1.93	*0.43*	2.29	*0.70*
II	6	30	2.50	*0.70*	2.76	*1.14*	1.23	*0.42*	1.58	*0.82*	1.88	*0.53*	1.89	*0.62*
II	6	60	2.22	*1.14*	2.19	*1.17*	1.38	*0.47*	1.48	*1.10*	1.44	*0.18*	1.87	*1.41*
II	6	90	2.06	*1.56*	1.71	*0.85*	0.97	*0.35*	1.07	*0.51*	1.42	*0.60*	1.40	*0.73*

Group I: Right carbon implant/left bony defect control.
Group II: Right carbon implant/left polyester implant.

would have occurred after breakage of the periosteum on removing the cylindric piece from the radius. Undoubtedly, these synostoses represent the first stage in the healing of bone defects of the rabbit radius. For us, it was essential to search for an experimental model in which the defect would be repaired in order to discover the relationship between the osteoid and the implant, leaving other models involving a more difficult healing for later studies.

The literature describes cases of intolerance to the carbonated material with respect to surface implantation (Amis et al. 1984, Jenkins and McKibbin 1980). In our series, 3 animals were seen to reject the carbon implants. Because they were the first that were operated on, we feel that the rejection might have been due to a technical error, leaving the fibers too close to the surface. Of these animals, only 1 showed an appreciable decrease in radiographic repair. Because this decrease was also noted in the control group, it could well reflect a problem of individual susceptibility.

Like Minns et al. (1982), we found that the repair of the defect around and intermingled with the implanted carbon fiber included new bone and a matrix of collagen fibers. The osteoid invasion of the implant occurred towards the end of the experiment. This is consistent with the findings of Alexander et al. (1981), Claes and Neugebauer (1985), and Weiss et al. (1985) regarding bone growth between carbon fibers in the zones in which the ligament prostheses have been inserted. The difference in the caliber of both kinds of fibers used in our study might account for the better penetration of the bone tissue into their filaments.

Although the degree of connective tissue repair was similar to that reported by Jenkins et al. (1977), we do not believe that the bone repair was facilitated by placement of inert nonreabsorbable implantation material, because the healing was very similar in all three procedures. From the results, it may be inferred that carbon and polyester fibers acted as a support or a seat for the repair.

In conclusion, carbon and polyester fibers may serve as biocompatible scaffolds for connective and osseous repair. However, their clinical usefulness is limited by their mechanical and biological properties.

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