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A SYNTHETIC CARBON FIBER PROSTHESIS FOR RECONSTRUCTION OF THE ANTERIOR CRUCIATE LIGAMENT IN CANINE KNEES - RADIOLOGICAL AND PATHOHISTOLOGICAL PICTURE

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The biological response and strength of a reconstruction of the anterior cruciate ligament (ACL) by carbon fibers was investigated in the canine knee. The allografts were inserted to replace the ACL according to the technique recommended by the manufacturer of the carbon fiber prostheses. The clinical radiological and pathohistological picture of the neoligament and bone-neoligament-bone connections were evaluated at one, two and six months later. Clinically and radiologically the knee joints were stable, without degenerative changes. Pathohistologically there were marked fibrous tissue ingrowth between the carbon fibers.

The canine knee is a suitable model for experimental knee surgery. The characteristics of the carbon ACL prosthesis are suitable in cases when an autograft (patelar tendon, semitendinosus-gracilis) cannot be performed in seriosly injured or elderly patients.

Key words: anterior cruciate ligament, carbon fiber prosthesis, experimental surgery, dogs, histological picture.

NTRODUCTION

The aim of our study was to investigate characteristics of the anterior cruciate ligament (ACL) neoligament after replacement of ACL with a carbon fiber prosthesis. It is a comparable situation to that in patients with a torn ACL and when the surgeon wishes to avoid the use of autografts, to spare the knee ligaments.

Various authors have reported the results of ACL replacement or reconstruction with allografts-artificial ligaments (Heerwaarden *et al.* 1996; Jenkins 1985; Strover and Firer 1985; Strum and Larson 1985; Cotton and Morrison 1985; Lemaire 1985.) or autografts (Groves 1980; Dandy and Hobby 1998; Burnet and Fowler 1985; Noyes *et al.*, 1983) in humans or experimental surgery, but there was no absolute agreement about the advantages of synthetic carbon fiber material and other prostheses over autografts, from the point of view of clinical, mechanical and histological evidence. Although, in our clinical experience autografts are supposed to be more favorable, there is the situation when patients are old, or one wishes to avoid donor site problems, when an artificial ligament must be used. Thus we made an experimental model with a carbon ACL prosthesis.

We investigated a carbon fiber prosthesis as an anterior cruciate ligament substitute with regard to the clinical, radiological and histological picture using the canine knee as the model. Carbon fiber /B.Braun Melsungen/ is a genuine prosthetic substitute designed to replace totally torn cruciate ligaments. The carbon prosthesis is made of 30-42000 fibers of 5-7 micrometers diameter, with height biocompatibility and fibrogenic potential (Goodship *et al.*1985; Kennedy 1983; Jenkins, 1985). We examined the above mentioned properties of the operated knees.

MATERIAL AND METHODS

Experimental animals: Fifteen (15) adult dogs (German shepherd) were divided in 3 groups (5 animals) of average body weight of 26 kg (from 19-32 Kg), were subjected to surgical procedures. The ACL were resected and then replaced with carbon fiber allografts.

Operative technique and postoperative care: All the operations were performed using aseptic techniques. The unoperated, opposite knee served as the control. All the dogs received a single dose of cephalosporine antibiotic as prophylaxis, and the surgery was caried out under general anesthesia using 50mg/ml of ketalar and 0.03 ml/kg of Combelen.

Medial arthrotomy was performed exposing the knee in order to excise sharply the ACL and replace it with a carbon fiber prosthesis. The prosthesis was placed through drill holes in the tibia and femur and joint space reproducing the normal isometric position of the ACL (Figure 1).

The bone tunnels were carefully prepared, smoothing sharp edges and pasting the ends of the allografts, which were fixed to the tibia or femur surface

Figure 1. Intraoperative intraarticular ACL placement of carbon prothesis

with proper size Blount staples. The prosthesis was tightened, manually, with the knee in 10 degrees of flexion.

After the operation knee stability was checked by the Lachman test. The knee was without cast protection, allowing free walking in the cage or while being taken for a walk. Postoperatively, every dog was evaluated for limp (by Kestner grade 1 to 4), range of knee motion and anterioposterior stability.

The radiological evaluation was done after 1, 2 and 6 months. It included observation of joint space narrowing, possible subchondral cyst, staple migration, osteophite presence, bone resorption and anteroposterior stability under manual stress (less than 3mm difference was considered as satisfactory), on the anteroposterior and lateral radiographs.

Macroscopic findings. After sacrifice the following details were analysed: the joint cartilage loss, carbon fiber debris spread, as well as width of the neoligament.

For pathohistological analysis of the replaced ACL at least 7 samples were taken from the intraarticular neoligament as well as from the femoral and tibial tunnel- attachments. Tissue pieces were fixed in 10% buffered formaldehyde, and embedded in paraffin blocks which were cut with a microtome in 5 micron thick samples. They were stained using the following techniques- Hematoxyllin-Eosin, Periodic Acid Schiff (PAS), Van Gieson, Paff Halmi, Masson trichrome, Alcina blue and Von Kossa. We investigated the intraarticular behaviour of the neoligament and tunnel ingrowth.

RESULTS

There were no significant pathological findings in the operated animals for the Laboratory findings (parametars of inflammation and toxicity). The degree of lameness decreased by the time (Table 1).

Table 1. The degree of lameness in operated dogs scale by Kestner, 1950)

Dog	Day 15	Day 60	day 180
1	3	2	2
2	2	1	0
3	1	1	1
4	3	1	0
5	2	1	1
6	3	1	
7	3	1	
8	2	2	
9	3	1	
10	2	1	
11	2		
12	1		
13	2		
14	2		
15	3		

Anteroposterior stability, rentgenographically recorded, showed a stable knee, with minimal anterior displacement during the Lachman test (mean values-4.16mm). There was a time dependent decrease of mean values at 1,2, 6 months due to maturation of neoligament .

On stress radiography there was a stable knee joint (Figure 2)

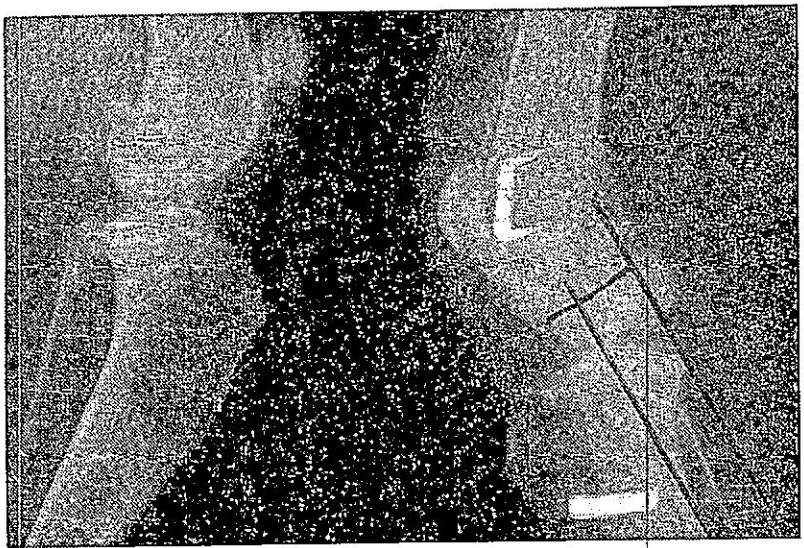

Figure 2. The stress radiographic picture showing minimal anterior shift picture of the stable knee joint.

Partial rupture of the allograft was established by macroscopic investigation in 3 of the 15 cases, regardless of the time interval. In the remaining 12 animals there was solid ingrowth of connective tissue around the prosthesis with the formation of a whitish membrane on the surface of the neoligament (Figure 3).

Dispersion of some carbon particles in the synovial membrane of the joint cavity occured in 2 of the 15 animals , but no significant changes of the articular cartilage or menisci were noted .

Pathohistological analysis of the slice of neoligament a month after the operation showed minimal fragmentation of the carbon fibers in the femoral and tibial bone tunnels. Around the carbon fibers, new proliferated connective tissue, hypercellular, with numerous fibroblasts and blood vessels were found. New connective tissue ingrowth through the spongious bone of the tunnels was also observed, but the reverse process did not happen (Figure 4).

In the second group of 5 dogs (sacrificed 2 months after surgery) new connective tissue, predominantly of the elastic type could be seen. Staining by the PAS method gave negative reactions .

In the third group, sacrifice 6 months after surgery, further ingrowth of new the connective tissue could be seen between carbon fibers on pathohistological

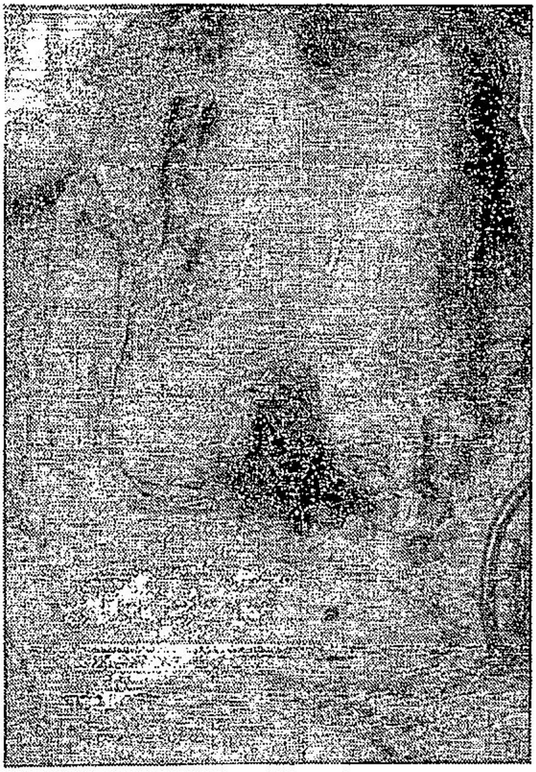

Figure 3. Appearance of a dog's knee joint preparation, 3 months after surgery, with solid on growth of connective tissue.

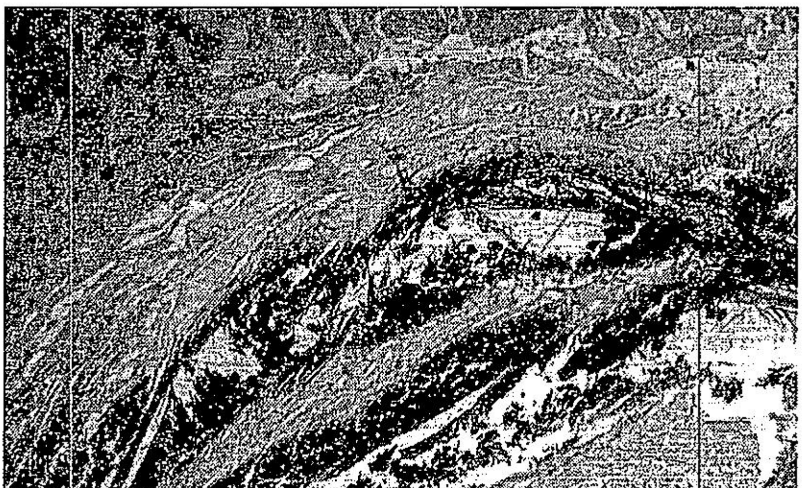

Figure 4. Histological picture of the allograft specimen, one month after the operation: new connective tissue with fibroblasts between carbon fibers isnide the bone tunnel, but without bone ingrowth into the neoligament (Hematoxylin-Eosin staining, under polarized light, magnification 10x25).

preparations from the femoral and tibial tunnels. Also in the central part of the neoligament numerous fibroblasts, fybrocites, lymphocytes and blood vessels were observed in the connective tissue (Figure 5).

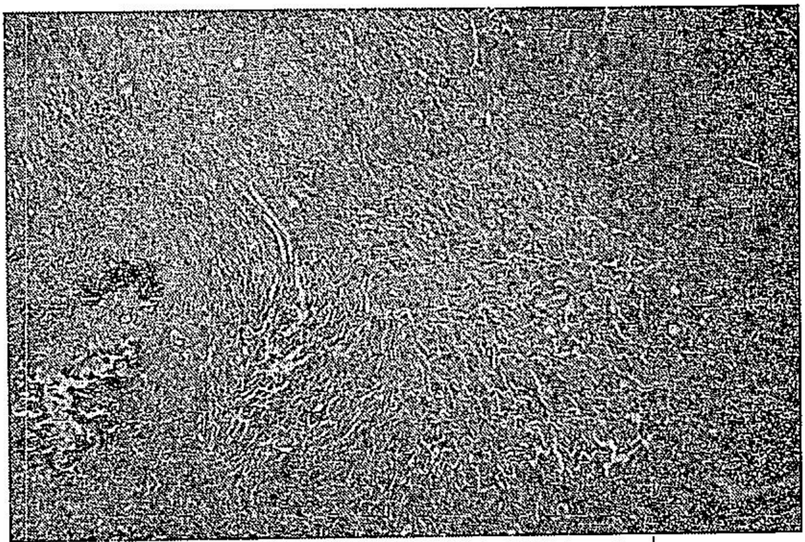

Figure 5. Large amount of new connective tissue around a few carbon fibers (HE 10X) 6 months after the operation.(Hematoxylin-Eosin staining, magnification 10x25).

DISCUSSION

The surgical procedure for allograft substitution of ACL is quite simple and there are no donor side effects, which are quite common after patelar tendon graft, resulting in anterior knee pain.

The techique was chosen both from the recommendation of manufacturer and data in the literature (Jenkins 1995; Strum and Larson 1985,). This is an intraarticular ligament reconstruction-procedure with complete substitution of the ACL and suitable surgical techniques for dog knees (Thorson *et al.*, 1989).

Although some recent studies claimed superiority of patelar tendon bone graft or semitendinosus-gracilis autografts, there is still no absolute agreement about the gold standard for ACL reconstruction, especially in doubtful patients. Our clinical experience of knee surgery showed that all kinds of ACL substitutes are valid and the final decision about which material should be applied is still that of the surgeon considering the individual characteristics of the patients (condition, age, etc).

Regarding clinical and laboratory parameters this procedure functions well, except for low grade intraarticular inflammation cells in the allografts, maybe due to immunological reactions. This good function of ACL allografts in dogs could be due to the prominent fibrous tissue response (Heerwaarden *et al.*, 1986; Lemaire

1985; Mendes *et al.*, 1985; Kennedy 1983.) which can explain the favourable knee stability which increased with time posoperatively.

This procedure stabilises the knee joint, in contrast to the situation when no ACL reconstruction or replacement is done (Clancy 1985; McDaniel *et al.*, 1983), which results in marked joint deterioration.

In the 6-month period most carbon fibers in the bone tunnels were torn apart which reflects the second major problem after fixation of the carbon device. This can be prevented to some degree with nochplasty. With time, all artificial ligaments (carbon fibers, Gore-Tex), tend to form wear particle-debris with an increasing percentage of synovitis, but when the neoligament consists mostly of new collagen tissuse- the carbon fibers serve as a temporary scaffold.

The carbon fiber allograft is strong enough, allowing fibrous ingrowth and maturation of collagen, but in our experiment the rate of maturation of young collagen was lower than in the studies of some other authors (Strover and Firer 1985; King and Bulstrode 1985; Shino *et al.* 1988). The post-operative joint laxity could be explained by the identification of some elastic fibers in our specimens.

It is clear that no ideal graft exists and according to Eriksson (1997), despite the numerous clinical-surgical, biomechanical and anatomical data , ACL reconstruction has not improved much over the past 20 years. Thus we must consider all the details mentioned above to obtain a good postoperative result.

All the presented data show that artificial ligaments (material) have a place in knee ligament reconstruction. This prosthesis is not ideal, but there is still room for improvement of the characteristics of the anterior cruciate ligament prosthesis to obtain a better and safer clinical outcome, especially because there is a group of patients which are not suitable for autograft ligament reconstruction and they need an artirficial ligament.

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REFERENCES

1. *Burnet QM, Fowler PJ*, 1985, Reconstruction of the anterior cruciate ligament - historical overview, *Orthop Clin North Am*, 16, 143-59.
2. *Clancy WG*,1985, Anterior cruciate ligament functional instability, *Clin Orthop*, 96, 6-9.
3. *Cotton FJ, Morrison GM*, 1985, Artificial ligament at the knee, *Clin Orthop*, 196, 4-6.
4. *Dandy DJ, Hobby JL*, 1998, Anterior cruciate ligament reconstruction, *J Bone Joint Surg, 80B*, 189-190.
5. *Eriksson E*, 1997, How good are the results of ACL reconstruction, Knee Surgery, Sports Traumatology, *Arthroscopy*, 137-138.
6. *Groves WH*, 1980, Operation for repair of the crucial ligaments, *Clin Orthop*, 147, 4-6.
7. *Goodship AE, Milcock SA, Shan JS*, 1985, The development of tissue around various prosthetic implants used as replacement for ligaments and tendons, *Clin Orthop*, 196, 61-7.
8. *Heerwaarden van RJ, Stellinga D, Frudiger AJ*, 1996, Effect of pretension in reconstruction of the anterior cruciate ligament with a dacron prosthesis. A prospective study. Knee Surgery, Sports Traumatology, *Arthroscopy*,: 202-209.
9. *Jenkins DHR*, 1985, Ligament induction by filamentous carbon fiber, *Clin Orthop*, 196, 86-8.

10. *Kennedy JC*, 1983, Application of prosthetic to anterior cruciate ligament reconstruction and repair, *Clin Orthop*, 172, 126-8.
11. *King JB, Bulstrode C*, 1985, Polylactate-coated carbon fiber in extraarticular reconstruction of unstable knee, *Clin Orthop*, 196-8.
12. *Lemaire M*, 1985, Reinforcement of tendons and ligaments with carbon fibers, *Clin Orthop*, 196, 169-74.
13. *Mc.Daniel WJ, Dameron TB*, 1983, The untreated anterior cruciate ligament rupture, *Clin Orthop*, 172, 158-64.
14. *Mendes DG, Iusim M, Angel D*, 1985, Histologic pattern of biomechanic properties of carbon fiber-augmented ligament tendon, *Clin. Orthop*, 196, 43-51.
15. *Noyes FR, Butler DL, Paulos L.E*, 1983, Intra-articular cruciate reconstruction, *Clin orthop*, 172, 71-7.
16. *O' Donoghue DH, Rockwood CA*, 1971, Reapair and reconstruction of the anterior cruciate ligament in dogs, *J Bone Joint Surg*, 710-8.
17. *Shino K, Inoue M, Horibe S*, 1988, Maturation of allograft tendons transplanted into the knee, *Jof Bone Joint Surg*, 556 - 60.
18. *Strover AE, Firer P*, 1985, The use of Carbon fiber implants in anterior cruciate ligament surgery, *Clin. Orthop.* 196, 88-97.
19. *Strum GM, Larson RL*, 1985, Clinical expirience and early results of carbon fiber augmentation of anterior cruciate recontruction of the knee, *Clin Orthop*, 196, 124 -37.
20. *Thorson E., Rodrigo JJ, Vasseur*, 1989, Replacement of the anterior cruciate ligament, a comparison of autograft and allograft in dogs, *Acta Orthop Scandin*, 60: 555 - 63.

SINTETIČKA KARBONSKA PROTEZA U REKONSTRUKCIJI PREDNJEG UKRŠTENOG LIGAMENTA KOLENA PSA - RADIOLOŠKA I HISTOLOŠKA SLIKA

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SADRŽAJ

U okviru ovog rada vršeno je ispitivanje biološkog ponašanja i čvrstine prednjeg ukrštenog ligamenta koji je zamenjen karbonskom protezom. Procenjivana su klinička, radiološka i patohistološka slika neoligamenta i njegovog spoja sa kostima, u periodima od 1, 2 i 6 meseci. Klinički i radiološki koleno je bilo stabilno, bez degenerativnih promena. Histološki je bilo izraženo prorastanje vezivnog tkiva oko karbonskih vlakana.

Koleno psa je odgovarajući model za eksperimentalnu hirurgiju kolena. Karakteristike karbonske LCA proteze su podesne u slučajevima kada autograft (ligamenta patele ili m.semitendinosus - gracilisa) nije dostupan, kod obimnijih povreda ili starijih pacijenata.