Strength of implanted carbon fibers

Studies of the lumbar spine in goats

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The L3–4 supraspinous and interspinous ligaments in 10 goats were replaced with carbon fibers stabilized with silk-suture seizing. The implants were removed after 3 weeks in 5 animals and after 3 months in the other 5. The maximum traction strength of nonimplanted slings was 157±9 kg (M±SD). After implantation, the strength was reduced to 136±17 kg, and after 3 months to 107±9 kg. However, the maximum strength of the spinous processes was 71±19 kg, which was less than the strength of 3-month implants. We concluded that the carbon fiber sling stabilized with silk sutures could be used for replacement of the interspinous ligament.

Carbon fibers may be used for replacement of extraarticular ligament tissue. They serve as a scaffolding for fibroblasts that in time build up a new ligament (Jenkins et al. 1977). The strength of such implants has been assessed in only a few studies, and never in the spine. The implant fixation seems to be a central technical problem. Mostly attachment to bone has been used (Neugebauer and Burri 1985, Weiss et al. 1985, Strover and Firer 1985, Witvoet and Christel 1985). Only Jenkins and McKibbin (1980) originally tried to attach their carbon fibers by using a knot; recently, they have stabilized the knot with tissue glue (Evans et al. 1987).

The present study was planned to test the strength of a carbon-fiber knot secured with silk sutures and to find out whether the carbon-fiber sling was strong enough when using the spinous processes as anchoring points.

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Material and methods

Under general anesthesia (Halothane) the spinous processes of L3 and L4 in 10 adult goats were freed and the supraspinous and interspinous ligaments were totally excised. A flexible carbon-fiber ligament (Jenkins ligament®, Johnson & Johnson Ltd., UK) was used. The ligament substitute consists of a twist having 40,000 graphite filaments with a diameter of 7–8 microns each. Unfolding the twist gives 20,000 filaments per cross-sectional area, which was the way the carbon-fiber ligament was used in the present study. The implant has no additives or coatings. The carbon fibers were looped around the spinous processes of L3 and L4 and were tied with a square knot strengthened with locking silk No. 1 knots (Figure 1). After closure of the wound in anatomic

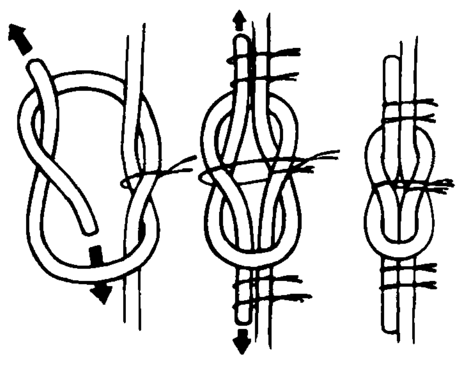

Figure 1. Technique for tying a carbon-fiber knot with additional stabilizing silk sutures.

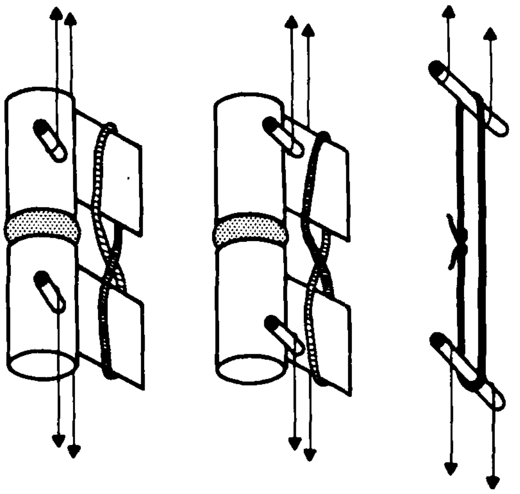

Figure 2. Test of carbon-fibers implanted in the lumbar spine in goats.
A. Traction applied to the entire lumbar segment through parallel steel bars drilled through the vertebral bodies.
B. After fracture of the vertebral bodies, traction was applied to the spinous processes via steel bars.
C. After breakage of the spinous processes, the carbon-fiber sling was carefully removed and tested for maximal traction strength.

layers and postoperative care, the animals were taken back to the farm.

Six nonimplanted carbon-fiber slings with the square knot were tested for maximal traction strength (Instron machine). The results were compared with those from implanted carbon-fiber slings harvested 3 weeks and 3 months after the implantation. Furthermore, the entire segment with carbon fibers implanted for 3 months was tested for maximal traction (Figure 2).

1. Steel bars 4.5 mm in diameter were drilled horizontally in the frontal plane through the middle of the third and fourth lumbar bodies, and traction was applied to the bars.
2. The same specimen was mounted again, now with the transverse steel bars placed through the third and fourth spinous processes, and tested in traction.
3. Finally, the implanted carbon-fiber sling was carefully removed from the specimen (macroscopically the sling was always intact) and tested for maximum traction strength.

For statistical analyses, the t-test and the paired t-test were used.

Results

All the animals tolerated the operation and the implant well. There were no infections. The maximum traction strength of the six nonimplanted carbon-fiber slings was 157±9 kg (mean±SD). Five slings broke in the substance and one in the knot. Figure 3 illustrates the high traction stiffness and sudden rupture of a carbon-fiber sling compared with the more stepwise failure of the bone structures.

After 3 weeks of implantation, the maximum traction strength of the carbon-fiber sling was 136±17kg; this was not different from the strength of nonimplanted slings. All five specimens broke in the substance, none in the knot.

After 3 months of implantation, the maximum traction force of the slings was 107±9 kg, which was lower than that of the nonimplanted slings ($P < 0.05$), but not different from the strength of 3-weeks implanted specimens.

When traction was applied to the vertebral bodies 3 months after carbon-fiber sling implantation, fracture of the lumbar bodies occurred at a maximum traction strength of 109±25 kg. This was not different from the maximum strength of the 3-month implanted carbon fibers.

The spinous processes showed a maximum traction force of 71±19 kg, i.e., lower than that of the vertebral bodies ($P < 0.05$) and the carbon-fiber slings ($P < 0.01$, paired t-tests).

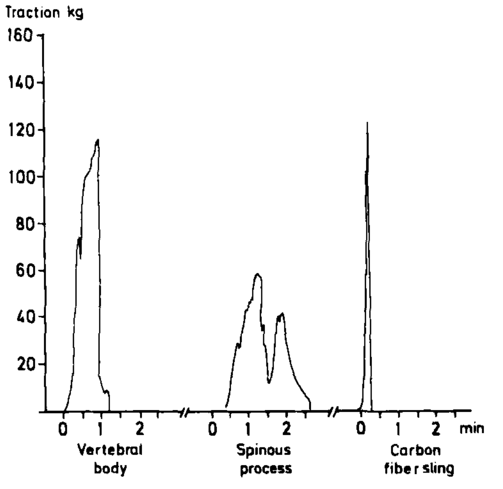

Figure 3. A typical example of the pattern of breakage of the vertebral bodies, the spinous processes, and the carbon-fiber sling tested in an Instron machine. Notice the abrupt rupture of the carbon-fiber sling compared with the more stepwise and elastic pattern of the bone.

Discussion

The fixation of the carbon-fiber sling to skeletal structures is still a problem (Neugebauer and Burri 1985, Weiss et al. 1985, Strover and Firer 1985, Witvoet and Christel 1985). Locking of the sling to itself seems necessary where fixation to bone is awkward, especially because fixation to fibrous structures alone is insufficient without simultaneous bone anchoring. On the other hand, passing the carbon fibers through bone jeopardizes the filaments because of their brittleness (Lipka and Ranu 1986). Unsupported carbon-fiber knots seem to slip (Jenkins and McKibbin 1980).

In the present study, the square knot was secured by locking the sling to itself on either side of the knot and at the knot using three silk sutures; sailors call it seizing, None of the knots locked in this way showed any sign of slipping during the 3-week and 3-month test periods. This was also evidenced by the fact that the traction tests with the carbon-fiber sling in situ resulted in bone fracture leaving the carbon-fiber sling macroscopically intact. In fact it seemed that the strength of the carbon-fiber sling was of the same magnitude as that of the entire segment, and it was stronger than the structures that were used as anchoring points for the carbon-fiber sling. However, the maximum traction strength of the 3-month implants carbon-fiber sling was decreased compared with the nonimplanted carbon-fiber sling. This could be caused by an increase in the number of fractured carbon filaments with time, which may be the implication of other authors who have shown a weakening of 3-month carbon-fiber implants (Alexander et al. 1983), although they, following this period, found the composite of carbon fibers and ingrown tissue to get stronger again. Another possibility is that the weakening of the carbon-fiber sling after 3 months of implantation was a result of the set-up where the carbon fibers were tested submaximally twice before the final test. The two first traction tests in bone may have broken a considerable number of the carbon filaments in the sling even if this was not macroscopically detectable. However, it seems that carbon fibers tied with our technique may be used as a replacement for interspinous ligaments.

References

Alexander H, Weiss A B, Parsons J R. Absorbable polymer-filamentous carbon composites – new class of tissue scaffolding materials. In: Alloplastic ligament replacement (Eds. Burri C. and Cleas L.) Hans Huber, Bern 1983:78–91.

Evans P D, Pritchard G A, Jenkins D H R. Carbon fiber used in the late reconstruction of rupture of the extensor mechanism of the knee. Injury 1987;18(1):57–60.

Jenkins D H, Forster I W, McKibbin B, Ralis Z A. Induction of tendon and ligament formation by carbon implants. J Bone Joint Surg (Br) 1977;59 (1):53–7.

Jenkins D H, McKibbin B. The role of flexible carbon fibre implants as tendon and ligament substitutes in clinical practice. A preliminary report. J Bone Joint Surg (Br) 1980;62(4):497–9.

Lipka J M, Ranu H S. The role of carbon fibres in orthopaedic implants: A review. In: Materials sciences and implant in orthopaedic surgery (Eds. Kossowsky, R. and Kossovsky, N.) Nijhoff Publ. Dordrecht 1986:335–43.

Neugebauer R, Burri C. Carbon fiber ligament replacement in chronic knee instability. Clin Orthop 1985;(196):118–23.

Strover A E, Firer P. The use of carbon fiber implants in anterior cruciate ligament surgery. Clin Orthop 1985;(196):88–98.

Weiss A B, Blazina M E, Goldstein A R, Alexander H. Ligament replacement with an absorbable copolymer carbon fiber scaffold – early clinical experience. Clin Orthop 1985;(196):77–85.

Witvoet J, Christel P. Treatment of chronic anterior knee instabilities with combined intra- and extra-articular transfer augmented with carbon PLA fibers. Clin Orthop 1985;(196):143–53.

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