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Expanded polytetrafluoroethylene membrane for the prevention of peridural fibrosis after spinal surgery: an experimental study

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Abstract One of the most common complications of lumbar spine surgery is peridural fibrosis, a fibroblastic invasion of the nerve roots and the peridural sac exposed at operation. Peridural fibrosis may produce symptoms similar to those the patient experienced preoperatively and, if another spinal operation is necessary, may increase the risk of injury at re-exposure. In a controlled study in dogs, we assessed the use of expanded polytetrafluoroethylene (ePTFE) as a barrier to postoperative invasion of fibrous tissue into the laminectomy defect. In 14 dogs, a two-level laminectomy was done, at L4-L5 and L6-L7. In 12 dogs, an ePTFE membrane was placed directly over the dorsal surface of the laminectomy defect at L4-L5 and within the defect (over the surface of the dura) at L6-L7. No material was implanted in two dogs (controls). Tissue for histologic studies was obtained from the controls and from ten dogs with the membrane 12 weeks

postoperatively. Two dogs with the membrane underwent reoperation. The study found that there was no peridural fibrosis in seven of the ten specimens in which the ePTFE membrane had been placed directly on the dorsal surface of the laminectomy defect, some peridural fibrosis in all specimens in which the membrane had been placed within the defect, and extensive fibrosis in controls. The ePTFE membrane created an excellent plane of dissection for reoperation. No foreign-body reactions to the membrane or membrane-related infections occurred. We conclude that the ePTFE spinal membrane, when properly implanted, is an effective barrier to postsurgical fibrous invasion of the vertebral canal. Clinical studies of use of this material in spinal surgery are warranted.

Key words Fibrosis · Spine · Polytetrafluoroethylene · Laminectomy · Dura · Peridural · Canine

Introduction

One of the most common complications of lumbar spine surgery is the postoperative appearance of peridural fibrosis (laminectomy membrane), a fibroblastic invasion of the nerve roots and the peridural sac exposed at operation [4–6] that was first described by Key and Ford [14]. The process of fibrosis hematoma from the surgical act and the healing of the paravertebral musculature reaches the posterior side

of the dural sac and the nerve roots, and may even engulf them. This would give rise, in turn, to a long and continued process of intra and periradicular fibrosis, giving rise to the symptomatology. Peridural fibrosis may produce symptoms similar to those the patient experienced preoperatively, leading to considerable morbidity [1, 6–8, 11]. In addition, if another spinal operation is necessary, the presence of fibrosis may increase the risk of injury at re-exposure [19]. Several different materials have been used experimentally and clinically in attempts to prevent peridural

fibrosis by providing a barrier to fibrous-tissue invasion into the vertebral canal, but the ideal material has not been found [2, 3, 8–10, 15–17, 19, 20, 23, 26–28, 30].

Recently, a study in 11 dogs by DiFazio et al. [6] found that an expanded polytetrafluoroethylene (ePTFE) membrane was more effective in preventing postlaminectomy peridural fibrosis than either free fat grafts, Silastic (Dow Corning, Midland, Mich.), or no material. We also used a canine model to assess the efficacy of the ePTFE membrane in preventing the entry of fibroblastic tissue into the vertebral canal after spinal surgery. However, both our method of anchoring the membrane and our technique for evaluating postoperative peridural fibrosis varied considerably from those used by DiFazio et al.

Materials and methods

Fourteen dogs of either sex weighing 25–38 kg were used in the study. All animals were cared for in a specifically prepared kennel at the Veterinarian School, University Aut6noma of Barcelona, in accordance with accepted standards. All surgical procedures were performed with the dogs under general anesthesia and continuous monitoring of vital signs.

In all dogs, a laminectomy defect of approximately 1 cm × 2 cm was created at both L4-L5 and L6-L7 with use of a burr. At L6-L7, the dural sac and the nerve roots were separated until the intervertebral disc was exposed. A transverse incision to the annulus fibrosus was made on the posterior longitudinal vertebral ligament, known in the human as the posterior longitudinal ligament. Curettage (scarification) of the intervertebral disc was performed in order to demonstrate, in this group, whether there actually existed a proliferation of fibroblasts from the intervertebral disc or whether it came only from the posterior healing.

In 12 of the dogs, the dorsal surface of the defect created by laminectomy at L4-L5 was covered with an ePTFE membrane (Preclude Spinal Membrane, WL Gore & Associates, Flagstaff, Ariz.; thickness, ~ 0.7 mm; porosity, ~ 3 µm), approximately 6 cm wide and 12 cm long. The graft was attached with four ePTFE CV-3 sutures (Gore-Tex Suture, WL Gore & Associates) to the capsule of the joint articulations, with the aim of preventing migration of the graft and thereby keeping the membrane in close apposition to the surface of the bone (Fig. 1). In the same 12 dogs, an ePTFE mem-

Fig. 1 Placement of expanded polytetrafluoroethylene (ePTFE; arrows) membrane at L4-L5 (C spinal cord, N nerve root)

Fig. 2 Placement of expanded polytetrafluoroethylene (ePTFE; arrows) membrane at L6-L7 (C spinal cord, N nerve root)

Table 1 Classification system for peridural fibrosis

Degree of fibrosis	Definition
Grade I	Absence of fibrosis
Grade II	Fibrosis not adherent to the dural sac or nerve roots
Grade III	Fibrosis adherent to the dural sac <i>or</i> nerve roots
Grade IV	Fibrosis adherent to the dural sac <i>and</i> nerve roots
Grade V	Fibrosis throughout the vertebral canal, encompassing the dural sac and nerve roots

brane was also inserted at L6-L7. At this site, the membrane was placed within the laminectomy defect and around the surface of the thecal sac, interposed between the disc and dura and encompassing the nerve roots (Fig. 2). In the remaining two dogs, no material was implanted.

Postoperatively, all dogs received antibiotic prophylaxis with 30 mg cefazolin per kilogram given intravenously every 8 h. A switch to oral antibiotics was made after 1 week. A neurologic examination was conducted within 48 h of the surgical procedure to rule out any medulloradicular effects; the segmental, myotatic, and flexor spinal reflexes were specifically evaluated.

Ten dogs with the ePTFE membrane and the two controls were killed 12 weeks after surgery and tissue obtained for histologic studies. The remaining two dogs with the membrane were reoperated on 12 weeks after the initial surgery for evaluation of difficulty in surgical dissection.

Longitudinal and transverse tissue sections were examined histologically after staining with hematoxylin-eosin and Goldner's trichrome. Peridural fibrosis in the vertebral canal was evaluated according to a classification system that incorporates both the extent of fibrosis and the degree of adhesion to the nerve structures (Table 1).

Due to problems of equipment availability we were unable to carry out MRI controls on the different experimental models.

Results

Postoperatively, all dogs had normal segmental, myotatic, and flexor spinal reflexes. None had incontinence of the sphincters or any sensory alteration. One skin infection

Table 2 Histologic results, according to the fibrosis grading system shown in Table 1 (*ePTFE* expanded polytetrafluoroethylene)

Specimen	Degree of fibrosis				
	Grade I	Grade II	Grade III	Grade IV	Grade V
Supralaminar ePTFE (L4-L5, <i>n</i> = 10)	7 (70%)	1 (10%)	2 (20%)		
Discal scarification + ePTFE within the defect ^a (L6-L7, <i>n</i> = 10)			3 (30%)	7 (70%)	
Controls (<i>n</i> = 4: L4-L5, <i>n</i> = 2; L6-L7, <i>n</i> = 2)					4 (100%)

^a Membrane was placed within the laminectomy defect and around the surface of the thecal sac, interposed between the disc and dura and encompassing the nerve roots

developed in a control. One dog had pelvic paresis in the immediate postoperative period, which resolved spontaneously without sequelae by 5 days after surgery.

In seven of the ten specimens in which the ePTFE membrane was placed directly on the dorsal surface of the laminectomy defect, the dural sac and the nerve roots were free of fibrous tissue. New bone in various degrees of maturation was observed in all ten specimens. Under the new bone, the dural sac and the nerve roots were normal in structure, and no fibrosis (grade I; Table 2) was present in the spinal canal (Fig. 3).

In two of the ten specimens from this group, fibrous tissue had penetrated the spinal canal through the space between the membrane and the margins of the laminectomy defect (grade III fibrosis). The fibrous tissue was closely adherent to the dorsal surface, but the nerve roots were free of fibrous tissue (Fig. 4). New-bone formation was evident beneath the implant. In no case did the fibrosis penetrate through the interstices in the ePTFE material. In the remaining specimen, a minimal amount of fibrosis (grade II) had entered the spinal canal but had not reached the dural sac or nerve roots.

In all ten specimens in which an ePTFE implant was placed within the spinal canal through the laminectomy defect, fibrosis had invaded the vertebral canal between the bone and the membrane. Three specimens showed grade III fibrosis (Fig. 5); seven had grade IV. No peridural fibrosis was observed around the disc lesion in any of the specimens in which an ePTFE membrane had been implanted, and only a moderate thickening of the common dorsal vertebral ligament was noted. There were no inflammatory or foreign-body reactions to the ePTFE membrane in any of the specimens.

In contrast to the findings in the dogs in which the ePTFE membrane had been implanted, the four specimens from the two control dogs (L4-L5 and L6-L7 from both) all had dense fibrous tissue that extended to the inside of the spinal canal and encompassed both the dural sac and the nerve roots (grade V fibrosis; Fig. 6).

In none of the specimens from L6-L7 (treated or control animals), in which scarification of the disc as well as laminectomy had been done, were there any signs of fibrosis at the disc lesion site at any point along the common dorsal vertebral ligament. These findings indicate that all

the fibrotic tissue present originated from the paraspinal muscles.

In the two dogs that underwent reoperation, removal of the ePTFE implant at L4-L5 revealed that the vertebral canal was completely closed by a layer of new bone (Table 3). Beneath that bone, the dural sac and nerve roots were normal. At L6-L7, where the ePTFE membrane was placed within the spinal canal and on the surface of the dura, no bone regeneration was observed at the laminectomy defect; however, there was no fibrosis in the dural sac or nerve roots. In addition, there was an excellent plane of dissection between the ePTFE membrane and the neurologic structures.

Discussion

The purpose of this study was to evaluate the efficacy of an ePTFE membrane, implanted with two different methods, in preventing postsurgical peridural fibrosis in a canine model of laminectomy. We found no evidence of fibrous tissue invasion in seven of the ten specimens in which the ePTFE membrane had been placed on the dorsal surface of the laminectomy defect, some degree of peridural fibrosis in all ten specimens in which the membrane had been placed within the bone defect, and extensive fibrosis in animals in which no membrane had been inserted. New-bone tissue was observed beneath the ePTFE membrane in all dogs in which the implant had been placed on the dorsal surface of the defect (Fig. 3). This is not fully applicable to human beings, as there is less plastic regenerating capacity of the laminectomy defect. On the other hand, as we showed in all the histologic images, the laminectomy closure was achieved because the ePTFE membrane prevented fibroblast penetration into the laminectomy defect. Furthermore, in the first 3 postoperative weeks, the period when fibroblast penetration takes place, the bone consolidation process had not closed, which allows us to assume that it is the application of the ePTFE membrane and not the closure of the bone defect that prevents invasion. We did not observe any instances of anterior fibrosis produced by a lesion created on the annulus fibrosus.

Thus, we found that the ePTFE membrane, when properly implanted, was an effective barrier against postsurgi-

Fig. 3 Specimen from dog in which the ePTFE membrane was implanted at L4-L5. The laminectomy defect is closed under the membrane by new bone formation. No peridural fibrosis is present (original magnification $\times 25$, Goldner's one-step trichrome stain)

Fig. 4 Specimen from dog in which the ePTFE membrane (M) was implanted at L4-L5. A small amount of fibrous tissue has penetrated through the space between the membrane and the bone limits (arrows) of the laminectomy (C spinal cord) (original magnification $\times 25$, modified Goldner's trichrome stain)

Fig. 5 Specimen from dog in which the ePTFE membrane (arrowheads) was implanted at L6-L7. A moderate amount of fibrous tissue (F) has entered the vertebral canal through the space between the membrane and the bone. The fibrosis has not reached the nerve roots (arrows) (original magnification $\times 10$, modified Goldner's trichrome stain)

Fig. 6 Control specimen. Fibrous tissue (F) surrounds both the dural sac (arrowheads) and the nerve roots (original magnification $\times 25$, modified Goldner's trichrome stain)

Table 3 Surgical macroscopic evaluation

Specimen	Findings at surgery
Supralaminar ePTFE (L4-L5, $n = 2$)	Bone regeneration (no fibrosis)
Discal scarification + ePTFE within the defect (L6-L7, $n = 2$)	No bone regeneration (no fibrosis)

cal fibrous invasion of the vertebral canal. Our results indicate that, during implantation, the entire laminectomy defect should be covered by attaching the membrane to the capsular tissue of the facet joint. Fixation to the capsule is safer and more secure than fixation to the periosteum and ligamentum flavum, and should avoid migration of the membrane. It is also technically easier and clinically practical. We found that if the membrane is placed within the spinal canal and wrapped around the dura and nerve roots, fibrosis may penetrate the space between the membrane and the bone margins of the laminectomy defect. Further attention should be given to improving the implant fixation method, however, because our histologic studies revealed that the minimal peridural fibrosis observed in the dogs in which the complete-coverage technique was used entered the vertebral canal through small spaces between the ePTFE membrane and the laminectomy margins. In those animals, therefore, the membrane did not in fact completely cover the laminectomy defect.

The development of new bone in the laminectomy defect in all dogs in which the ePTFE membrane was implanted directly on the dorsal surface of the defect may have been facilitated by the presence of the membrane, which, by creating a barrier to peridural fibrosis, allowed normal bone regeneration to proceed unimpeded. Other factors may have been the small size of the laminectomy and the special characteristics of canine bone metabolism.

In contrast to what might be expected in the light of the theory of the origin of postoperative peridural fibrosis proposed by Key and Ford [14] and Songer et al. [27], no anterior fibrosis resulting from the lesion in the annulus fibrosus was observed in any dog in this study. Instead, our findings support the theory of LaRocca and MacNab [18], who maintained that the scar tissue that invades the vertebral canal after spinal surgery originates in the damaged paraspinal muscle. The origin of peridural fibrosis is probably multifactorial. In particular, inflammation in response to surgical trauma to the cells that cover the dural sac may also be involved.

The results of our experimental study, which is, to our knowledge, the second to examine the effectiveness of an ePTFE membrane as a barrier to peridural fibrosis, support those of DiFazio et al. [6], although the two investigations differed in two principal ways. We anchored the implant by suturing it to the capsule of the facet joints, whereas DiFazio and colleagues sutured the membrane to the periosteum and the yellow ligament. We believe that our

method is less technically difficult. We and DiFazio et al. also used different methods of assessing the degree of peridural fibrosis. They used the system described by Nussbaum and co-workers [24], which evaluates the extent and density of the fibrosis separately. This system uses the presence or absence of contact between the dural sac and the fibrosis to define density, and as a measure of extent, it only defines the limit values of the classification, without defining intermediate values. We think that the important thing is to establish and use a classification that defines clearly and easily the presence or absence of fibrous tissue in the spinal canal, and its adherence to the latter's noble structures. In contrast to the Nussbaum system, our five-part classification system provides an overall assessment of the quantity and nature of any peridural fibrosis present and includes information about its adhesion or non-adhesion to nerve roots and the dural sac.

Our study did not include a comparison of the efficacy of the ePTFE membrane and other barrier materials in preventing postoperative peridural fibrosis. Materials that have been used clinically to curtail fibrosis after spinal surgery include Silastic [19] Gelfoam (Upjohn, Kalamazoo, Mich.) [18], and polyglactin 910 [24]. The most commonly used materials are autologous fat grafts, but the results achieved have been variable with respect to both efficacy [8, 21] and safety [22, 25]. In experimental studies, some promising preliminary results have been achieved with polyvinyl alcohol hydrogel membrane [10], carbohydrate polymer [26], and sodium hyaluronate [28]. We chose to investigate the membrane form of ePTFE because of its excellent record of biocompatibility and its ability to minimize adhesions [12, 13, 29]. Although large, long-term, randomized clinical trials of the use of the ePTFE membrane in spinal surgery are needed to confirm its usefulness, our experimental and clinical (unpublished data) results with this device have been excellent, and we currently implant ePTFE membranes in all our patients who undergo laminectomy.

Conclusions

In a controlled study in a canine model, implantation of an ePTFE membrane directly on the dorsal surface of the bone defect resulting from laminectomy created a physical barrier that minimized postoperative penetration of fibrous tissue produced by scarring of the posterior musculature. No inflammatory or foreign-body reactions were observed. Maximal efficacy of the barrier material required special attention to implantation technique. Creation of lesions in the annulus fibrosus did not result in anterior fibrosis. In the dogs in which reoperation was performed, the presence of the ePTFE membrane created an excellent plane of dissection. Clinical studies involving use of the ePTFE membrane in patients undergoing laminectomy are needed.

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