In vivo biocompatibility testing of peek polymer for a spinal implant system: A study in rabbits

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Abstract: We are developing a new spinal implant system (SIS) without fusion (bone graft). This SIS is made from two materials, metal and polyetheretherketone (PEEK) polymer. The Food and Drug Administration recommended testing *in vivo,* in an animal model, whether the PEEK polymer could be used in a SIS without any harm of wear debris to the nervous tissue (spinal cord and nerve roots). The objective was to evaluate the biological response of the spinal cord and nerve roots (dura mater) to PEEK polymer particles. Twenty-four female New Zealand white rabbits were used. The rabbits were divided into three groups: test (n = 12), control (n = 9), and sham (n = 3). During the surgery, the test group received the PEEK particle injections (5×10^7 particles per site, lumbar and thoracic), while the control group received only the vehicle (0.9% saline solution). The sham group had the same surgical approach without injection. In each group, the rabbits were euthanized at 1, 4, and 12 weeks postsurgery. The macroscopic and semiquantitative histologic analyses of the spinal cords (dura mater) showed normal vascularization and particle adherence to the connective tissue especially at the injection sites. Neither necrosis nor swelling of the dura mater and nerve roots was observed. The PEEK polymer is harmless to the spinal cord; thus it might be used as component in the spinal implant system. © 2002 Wiley Periodicals, Inc. J Biomed Mater Res 62: 488–498, 2002

Key words: spine; biocompatibility; polymer; wear debris; nerve roots

INTRODUCTION

Polymer material is used with increasing frequency for treatment of joint instabilities and diseases. Unfortunately, after a long period of implantation the material can be a source of wear debris, especially when there is friction between two identical or different materials, such as polymer/polymer or polymer/metal. The polymer spinal devices available on the market, such as cages for the vertebral fusion and cervical plates, are used to maintain joint stability. Despite the mechanical constraints exerted on these implants, they are not liable to have significant friction such as one might find with the dynamic spinal implant used to correct a spine deformity such as scoliosis.

We are developing a new spinal implant system (SIS) to correct the spine deformity scoliosis without spine fusion (bone graft along the spine). Our SIS for the correction of scoliosis is made from metal and polyetheretherketone (PEEK). It is a dynamic spinal implant with micromotion of some components along the correcting rods, a concept that has never been used in the spinal implant. This state-of-the art spinal implant with micromotion and nonfusion allows the preservation of the physiology of the spine without jeopardizing its correction. Nowadays, the spinal implant systems on the market for the correction of a spine deformity (scoliosis) are static, made from a metal only, and spine fusion is mandatory. The use of PEEK polymer in our SIS is dependent upon its mechanical properties and biocompatibility.

The polymer materials used in the spinal devices (cages, plates) have not been tested for spinal cord alterations. There are few biocompatibility data available on the PEEK. The biocompatibility of PEEK polymer has been tested *in vivo*[1,2,3,4] and *in vitro*,[5,6] and suitable biological responses have been reported regarding the tissue and cellular compatibility. *In vivo* studies of PEEK biocompatibility have been conducted by testing the bone and soft tissue response to various implants. However, to our knowledge there is no study available regarding the PEEK polymer biocompatibility with nervous tissue (spinal cord and

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nerve roots). Our main interest regarding the safety of the SIS was to test the PEEK polymer biocompatibility with the nervous tissue. Taking into account the site of the implant we investigated whether the PEEK polymer might be used in a spinal device without any harm of wear debris to the spinal cord and nerve root tissues, especially the dura mater.

The objective of this work was to recreate *in vivo* the worst case scenario in terms of wear debris from a SIS by injecting a high concentration of PEEK particles into the spinal canal of an animal model. Thus, we evaluated a subchronic biocompatibility of PEEK polymer particles in the nervous tissue (spinal cord and nerve roots) in an experimental animal model, a rabbit.

MATERIALS AND METHODS

PEEK polymer particles

The SIS consists of two rods, five mobile chariots, and three fixed chariots. The cylindrical shape mobile chariot is made of metal and PEEK polymer as insert. The chariots are slipped on two rods and then secured to vertebral screws. A mechanical wear test was performed with a rod and mobile chariot to evaluate the life span of the implant (a cycle of 1 million is equivalent to 5 years). The chariots were tested for 2 million cycles. The polymer debris collected from the wear test were examined using scanning electron microscopy (SEM). The particles demonstrated two basic morphologies, rounded and fibril particles. The majority of particles measured were, on average, 50 μm, with some 5 μm. Thus, the particle size of the PEEK polymer tested on rabbits was based on the mechanical wear test, which simulates the outcome of the SIS after 5 to 10 years implantation.

Medical grade PEEK powder (Unfilled PEEK polymer, 150 g) was commercially obtained in a size of 40 μm in diameter that contains 5% of 5 μm size particles (Victrex USA Inc., Spartanburg, SC). Morphologically the commercial particles were more rounded than fibril. Because there is no study in the literature regarding this topic, the concentration of injected particles was based on previous work in rats where different wear particles were injected in the knees of the animals.[7] The implantation site (spinal canal) and the well being of the animal were taken into consideration regarding the particle concentration. The concentration chosen was the worst case scenario, and probably will never be found at the implantation site of any spinal implant. The number of particles was calculated from the volume of a sphere, $V = \frac{3}{4}\pi r^3$, where r equals the radius of the sphere, and from the density of the particles. The density of PEEK powder is 1.29 g/cm^3. The preweighed PEEK powder in polyethylene 2 mL tubes was sterilized by steam autoclave. The particles were suspended in a 0.9% sodium chloride irrigation, USP (saline solution; Baxter, Toronto, Canada). The volume injected at each site was 200 μL containing about 50×10^6 particles.

Animal experimental design

The protocol of the animal study was approved by the ethics committee on Animal Research at the research center at Sainte-Justine Hospital (Approval 98-11). The Canadian Council on Animal Care (CCAC, 1980–1984) guidelines for the care and use of experimental animals were observed.[8]

The guidelines of the Association for the Advancement of Medical Instrumentation (AAMI Standards) and [9] the ASTM standards F 763-87[10] and F 981-91[11] were followed for the implantation and the specimen retrieval.

Twenty-four female New Zealand white rabbits weighing from 2.5 to 3 kg were used as the experimental animals (Charles River Laboratories, St-Constant, Canada). The animals were given a mix of ketamine (30 mg/kg), xylazine (5 mg/kg), and Acepromazine maleate (0.5 mg/kg) as a preoperative intramuscular medication. After an endotracheal intubation, an anesthesia was maintained with 1.5% halothane and 1.5 L of 100% oxygen by means of a respiratory machine (Moduflex; Dispo-Med LTD, Joliette, Quebec, Canada).

The rabbits were destined to three main groups: test group PEEK (n = 12 animals), control group (n = 9 animals), and sham group (n = 3 animals). Each group was further subdivided according to postsurgery observation time periods before the sacrifice (1, 4, and 12 weeks; Table I). Four test animals, three control animals, and one sham animal were used per evaluation period for PEEK polymer, saline solution, and sham operation, respectively. All the animals were then prepared for histopathological comparison.

Surgical and postsurgical procedures

For the surgery, the animals were placed under general endotracheal anesthesia and positioned prone with their backs shaved and cleaned with a mixture of proviodine and alcohol (aseptic solution). Eye lubricant was used to avoid conjunctival drying (Lacri-Lube; Allercan Inc., Markham, Ontario, Canada). The surgeries were performed under strict sterile conditions. Incisions (4 cm) were made along the spine with a scalpel blade (#10) at midthoracic and midlumbar regions. In each incision two spinous processes were exposed, which was then followed by an excision of one spinous process at the thoracic level T10 and one at the lumbar level L3. The ligament flavum (yellow ligament) was cut with a scalpel blade (#11) at the two levels in order to facilitate access to the spinal canal. Before the injection, the PEEK powder was suspended in a 0.9% saline solution,

TABLE I
Animal Experimental Design for the PEEK Implantation

Group Identification	Observation Periods and Number of Rabbits		
	1 Week	4 Weeks	12 Weeks
Test: PEEK polymer injection	4	4	4
Control: saline injection	3	3	3
Sham operation: no injection	1	1	1

which was then shaken vigorously. An injection of a milky solution (5×10^7 particles per 200 μL injection at each site) was placed into the spinal canal at the lumbar L3 and thoracic T10 sites, respectively (Fig. 1).

The control rabbits underwent the same surgical procedure as the test rabbits. They received two injections of a saline solution into the spinal canal at the lumbar L3 and thoracic T10 sites, respectively (200 μL per injection). The sham rabbits underwent the same surgery as the test rabbits but without any invasion into the spinal canal.

The wounds were closed using absorbable sutures (2-0 Dexon) for muscles and 3-0 Dexon for subcutaneous tissue and skin. The closed wound was coated with a spray dressing (OpSite; Smith & Nephew Inc., Lachine, Quebec, Canada). For infection prophylaxis, intravenous injection of antibiotic cefazolin sodium (kefzol, 125 mg/kg) was performed pre- and postoperatively, and the analgesic Butorphanol (Torbugesic, 10 mg/kg, three doses) was given i.m. postoperatively for 24 h.

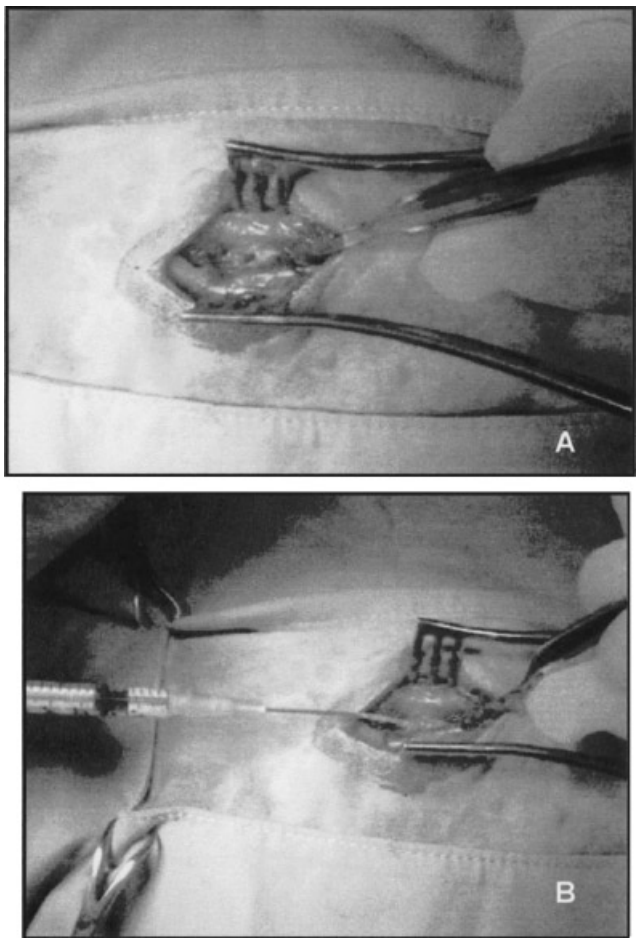

Figure 1. Surgical procedure and PEEK polymer injection. (A) The excision of the spinous process and ligamentum flavum (yellow ligament) facilitate access to the spinal canal. (B) The procedure was followed by the catheter insertion. The length of the inserted catheter is 1 cm. The particles were injected gradually (200 μL per site) at the lumbar and thoracic levels, respectively. The particle infiltration was helped by pulling up the spinous process, which is just above the injection site. The control animals underwent the same surgical procedure, but received only a saline solution (injection of 200 μL per site). The surgery was performed in a 1 h period.

All 24 rabbits survived the operation. In comparison of the two groups, control versus test rabbits, we did not notice any behavioral abnormality between the animals. Twelve hours postsurgery every rabbit was walking and eating normally without showing any discomfort. No paralysis was experienced during the observation period. All of the rabbits kept for 4 and 12 weeks postsurgery gained weight while the weight of those kept for 1 week postsurgery remained stable.

The animals received veterinarian-supervised care under the guidelines established by the Committee on Animal Research at the Research Center of Sainte-Justine Hospital. After the surgery the rabbits were kept in individual cages in order to prevent any excessive movement. They were fed daily with rabbit diet (5079 U.S. Charles River Rodent Animal Diet), and water was consistently available (*ad libitum*).

Fluoroscopy

The fluoroscopy experiment was performed on a living rabbit prior to the PEEK testing in order to assure us of the route taken by the injection into the spinal canal. A radioopaque solution (250 μL) was injected into the rabbit spinal canal at the thoracic and lumbar levels (Fig. 2). Radiographs were taken 10 to 15 s postinjection, and they revealed the solution's path into the spinal canal, which seemed to be in the direction of caudal to cranial.

Euthanasia and specimen retrieval

At the end of each observation period, the test, control, and sham operation rabbits were euthanized by a sodium pentobarbital (Euthanyl, 240 mg/mL, i.v. 2 mL/4.5 kg). The spinal cord from each rabbit was exposed carefully by means of orthopedic cutters by cutting the vertebral arch of both sides of the segment (Fig. 3).

The spinal cord was removed carefully from two segments (lumbar followed by the thoracic) by cutting the nerve roots with a narrowed scalpel (blade #10) (Fig. 4). This procedure was followed by the examination of the specimens under a low magnification lens for the evaluation of the tissue reaction to the PEEK polymer.

Once examined, the spinal cord segments from the thoracic and lumbar regions were fixed in 10% buffered neutral formalin for a 1 week period before their processing for histology.

Histology

The spinal cord lumbar and thoracic segments were sliced in serial blocks from caudal to cranial and embedded in paraffin according to standard dehydration and embedding techniques. From tissue blocks (thoracic and lumbar spinal

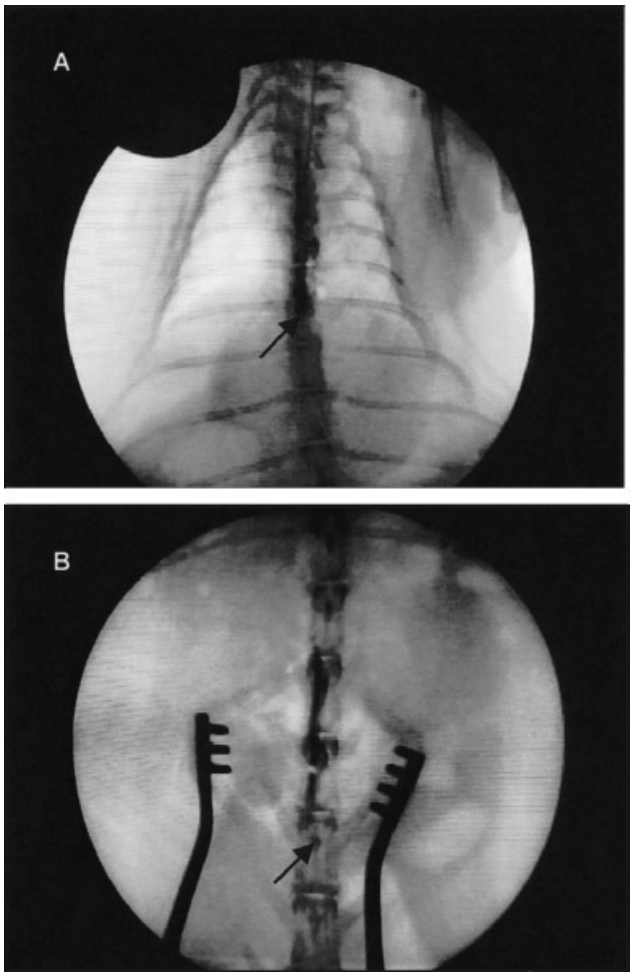

Figure 2. Injection of radio-opaque solution into the spinal canal. (A) At the thoracic level T10 (arrow), (B) at the lumbar level L3 (arrow). The radiograph was taken immediately after the injection. Note the solution path along the spinal canal (dark vertebrae). The injection was made from caudal (down) to cranial (up).

cord) of all animals, histologic sections 4 μm thick were prepared. For the examination with the light microscope, the sections were mounted on glass slides and stained with hemathoxylin-phloxin-saffron (HPS) stain. The histologic blocks, slides, and sections prepared and examined from the spinal cords retrieved from rabbits in this study are summarized in Table II.

Regarding the spinal cord tissue response evaluation to the PEEK particles, the method suggested by the ASTM standard F981-91 was followed.[11] The method followed by the ASTM standard F981-91 is based on the Turner et al. method.[12] Histological examinations involved scoring each of the criteria on a 0 to 3 scale based upon the relative prominence of each item as follows (ASTM F981-91 standard,[11] Table III). From gross observation of the implantation site, a score of[12]:

- "0" was given if one could not detect an abnormal appearance of the tissue surrounding the implant.
- "±" indicates a questionable or a very mild reaction of the tissue to the implant.

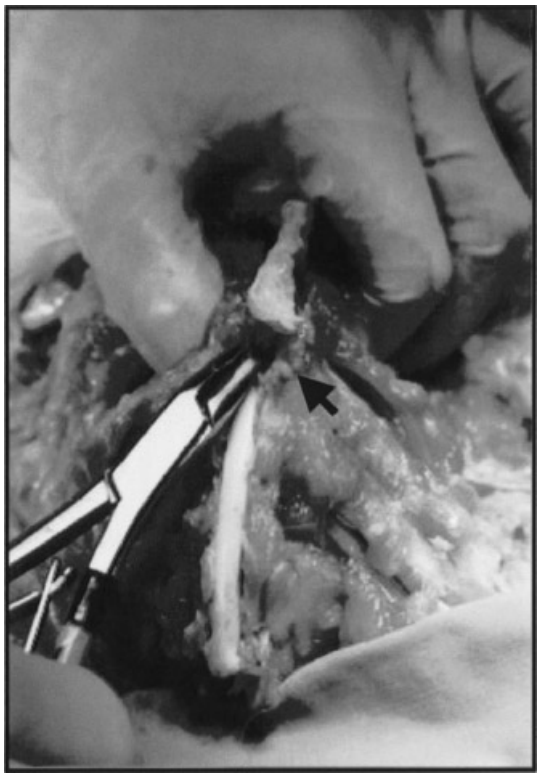

Figure 3. The clearance of the thoracic spinal cord from the spinal canal by cutting the vertebral arch of both sides of the spine segment (arrow).

- "1+," "2+," and "3+" represent increased degrees of tissue involvement surrounding the implant.

RESULTS

All surgeries were uneventful, with no complications. We did not experience any animal infection, paralysis, or mortality during the observation period. During the macroscopic and histologic evaluation, photographs and photomicrographs of the most representative spinal cord and material-related changes were taken.

Macroscopic findings: spinal cords

The biological response of the test rabbit spinal cord (PEEK injection) was evaluated macroscopically in comparison with the spinal cord of the sham operation and control rabbits. The spinal cords of the sham rabbits at 1, 4, and 12 weeks postsurgery were examined under a magnifying glass. They showed a normal appearance of the dura mater and nerve roots (normal vascularization of the dura mater and normal loose connective tissue around the spinal cord). The spinal

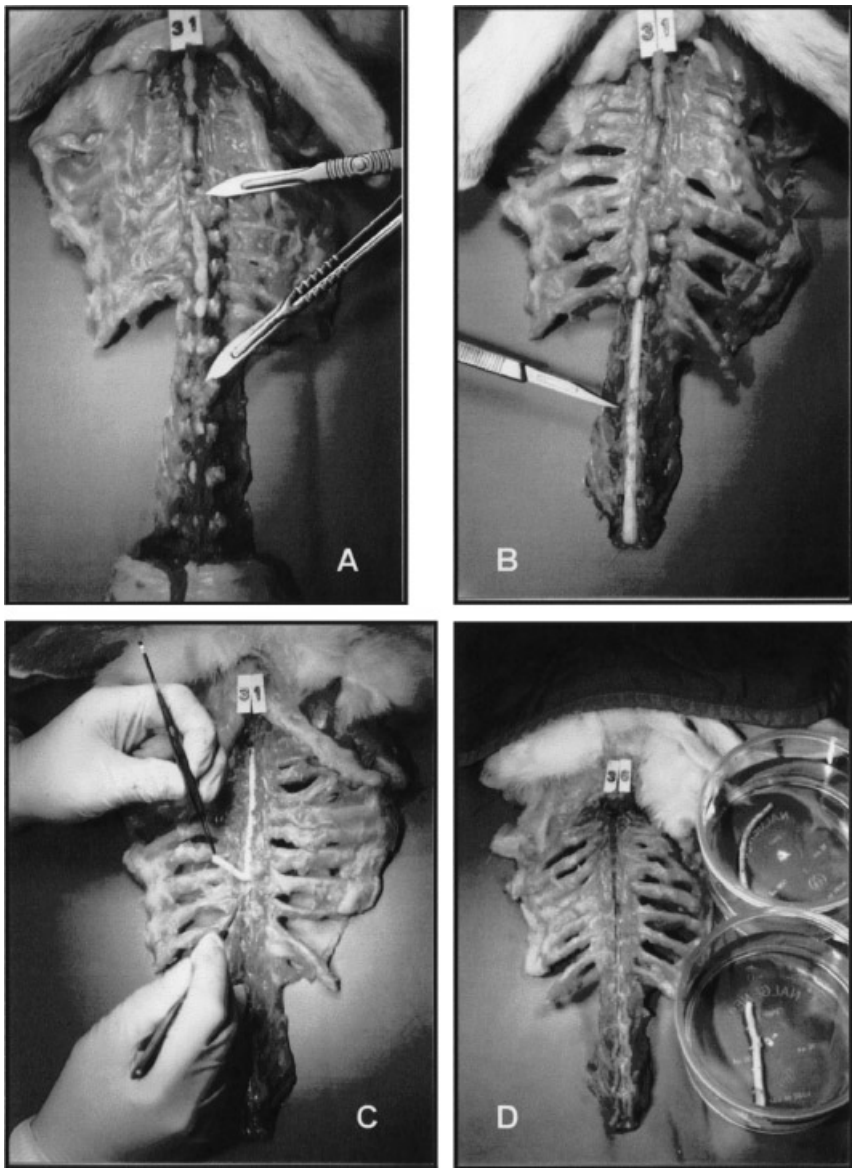

Figure 4. Spinal cord retrieval from a rabbit thoracic and lumbar spine. (A) The injection sites at the thoracic and lumbar regions (blades) and the excised spinous process at the injection sites. The spinal cord was cleared carefully (B). First, we exposed the lumbar spinal cord, the nerve roots were carefully cut with a scalpel, and (C) the procedure was repeated for the thoracic spinal cord. (D) The two spinal cord segments were macroscopically examined under a magnifying glass and fixed in 10% buffered formalin.

TABLE II
Histology Preparation and Analysis

Items	Total Number	Description
Rabbits	24	12 test, 9 control, 3 sham
Injection sites	2	1 thoracic T10, 1 lumbar L3
Block preparation/spinal cord	40 to 45 (0.5 cm/block)	Serial blocks from caudal to cranial (marked with an India ink on the cranial side)
Block analysis/spinal cord	12 to 16 blocks/spinal cord (6 to 8 blocks/site)	1 block of the injection site, 1 block caudal, and 4 to 6 blocks cranial to the injection site
Histologic slides/spinal cord	24 to 32 slides/spinal cord (thoracic and lumbar sites)	A total of 576 to 768 slides were examined (all 24 rabbits)
Histologic sections/slide	Average of 4 sections/slide	A total of 2304 to 3072 sections were examined (all 24 rabbits)

TABLE III
Scoring System for Tissue Response to the PEEK Particles

Evaluation of Cellular Elements		Evaluation of Necrosis		Evaluation of Toxicity	
Number of[a] Elements	Score	Degree	Score	Rating	Score
0	0	Not present	0	Nontoxic	0
1–5	0.5	Minimal present	0.5	Very slight toxic reaction	1
6–15	1	Mild degree of involvement	1	Mild toxic reaction	2
16–25	2	Moderate degree of involvement	2	Moderate toxic reaction	3
26 or more	3	Marked degree of involvement	3	Marked toxic reaction	4

[a]The scoring system of 0 to 3 is based upon the number of elements (inflammatory cell types) in high power field (×470), average of five fields.

cords of the control rabbits at 1, 4, and 12 weeks postsurgery showed the same pattern as the spinal cords of the sham rabbits, without any presence of necrosis at the injection sites or any swelling of the nerve roots.

One week postsurgery

The macroscopic examination of the test rabbit spinal cord 1 week postsurgery showed normal vascularization of the dura mater. Under a magnifying glass, there were few particles adhering to loose connective tissue at the injection site. Thus, no adverse reaction, such as necrosis, seemed to develop on the dura mater secondary to the particle injection. The nerve roots had the same appearance as those in the sham and control specimens.

Four weeks postsurgery

The macroscopic examination of the test rabbit spinal cords 4 weeks postsurgery showed a normal vascularization of the dura mater with little particle adherence to loose connective tissue. No adverse reaction (necrosis) seemed to develop on the dura mater secondary to the particle injection. The nerve roots had the same appearance as those in the sham and control specimens.

Twelve weeks postsurgery

The macroscopic examination of the test rabbit spinal cords 12 weeks postsurgery showed a normal vascularization of the dura mater, whereas the loose connective tissue was a little bit thicker at the injection site and in the immediate vicinity, as compared to the sham specimens and the 1- and 4-week test specimens. Under a magnifying glass, little particle adherence to the connective tissue was observed. No adverse reaction (necrosis) seemed to develop on the dura mater secondary to the particle injection. Connective tissue around the nerve roots at the injection site had no adverse reaction such as necrosis or swelling.

Histologic findings: spinal cords

The reactions of test rabbit spinal cord tissue to the PEEK implantation were evaluated histologically in comparison with the spinal cords of the control and sham rabbits. The PEEK particles were found in the histologic sections of the implantation sites. Polarized

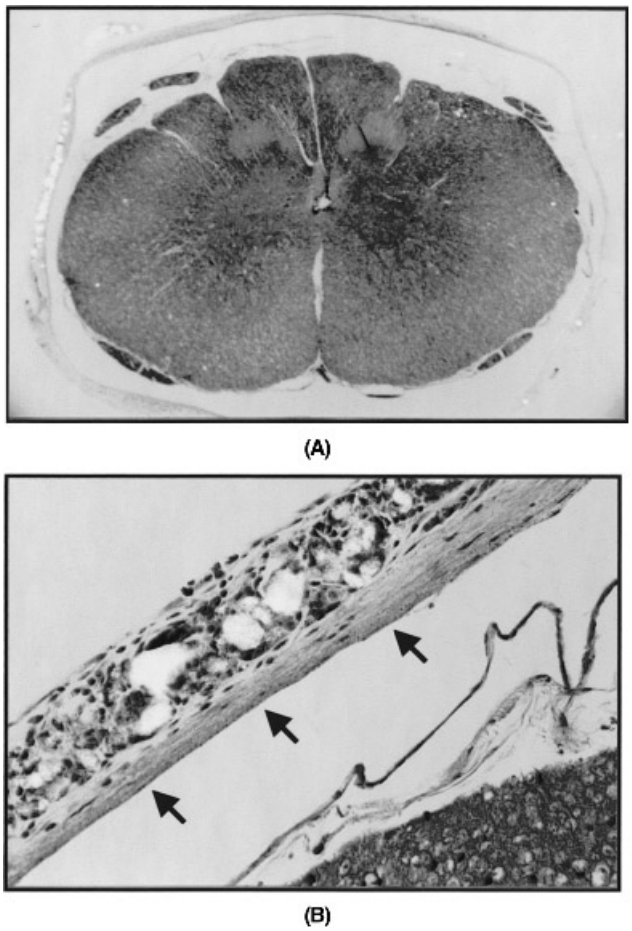

Figure 5. Polarized photomicrographs of test rabbit (a thoracic section nearby the injection site). (A) One week postsurgery showing particle adherence to loose connective tissue next to the dura mater. (B) Note in high magnification, the infiltration of inflammatory cells is limited to the dura mater (arrows). (HPS stain, original magnification ×31 and ×312, respectively.)

TABLE IV
Histopathological Evaluation of Rabbit Spinal Cord Tissue Adjacent to the PEEK Particles at Selected Time Intervals

Material	Peek		
Number of rabbits	4 Rabbits	4 Rabbits	4 Rabbits
Duration of implant (weeks)	1 Week	4 Weeks	12 Weeks
Gross response	0	0	0
Degree of necrosis	0	0	0
Inflammation	Mild	Mild	Mild (diminishing)
Polymorphonuclear leukocytes (white blood cells)	3 (Normal response to a foreign body)	3 (Less cells than in 1 week)	3 (Less cells than in 4 weeks)
Lymphocytes	1	0.5	0.5
Plasma cells	1	0.5	0.5
Macrophages	1	1	0.5
Giant cells	0.5	0.5	0
Foreign body debris	Particles	Particles	Particles
Fibrosis	0	1 (Mild degree, around the particles)	1 (Mild degree, around the particles)
Fatty infiltration	0	0	0
Relative size of involved area (mm)	6 to 10 mm	6 to 10 mm	6 to 10 mm
Toxicity rating	0	0	0

See Table III: Scoring System.

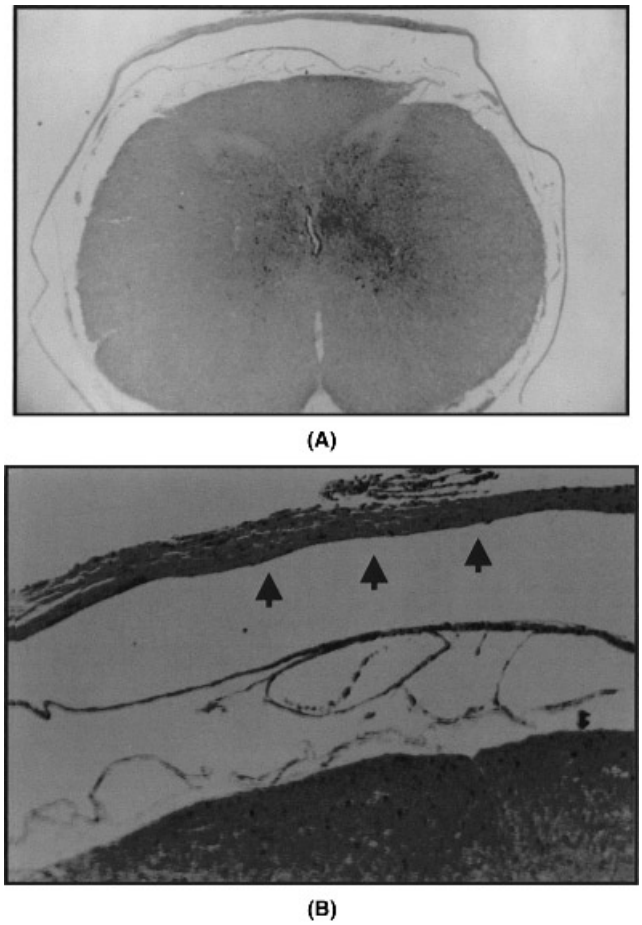

Figure 6. Light photomicrographs of a control rabbit, a thoracic section at the injection site. (A) One week postsurgery. (B) High magnification shows a very mild inflammation of the dura mater especially at the injection site (arrows). (HPS stain, original magnification ×31 and ×125, respectively.)

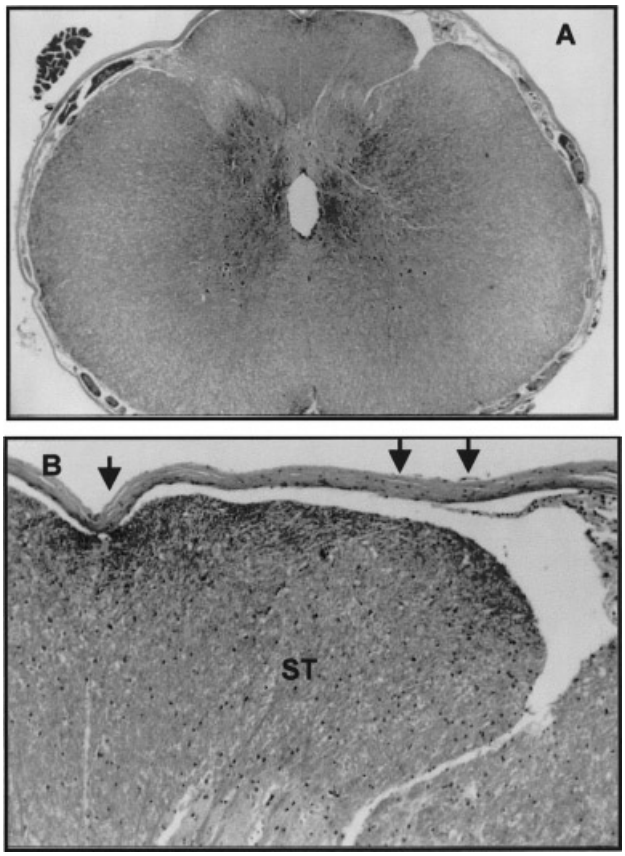

Figure 7. Light photomicrographs of a sham rabbit, a thoracic section. (A) One week postsurgery. (B) High magnification shows normal appearance of the nerve cells (spinal cord tissue, ST) and dura mater (arrows). (HPS stain, original magnification ×31 and ×125, respectively.)

microscopy was used to show the particles in all the test rabbits. The particles were located in the direct vicinity of the dura mater, but none in the spinal cord tissue, for all the observation periods (1,4, and 12 weeks). The particles seemed to adhere to the dura mater and to loose connective tissue surrounding the spinal cord. However, no severe inflammatory response was observed in any specimen (Figs. 5, 8, and 11). The biological response of the spinal cords, especially the dura mater, to the PEEK particles is summarized in Table IV.

Regarding the spinal cords of the control rabbits with a saline injection, the histologic section of the injection sites showed a very mild reaction of the dura mater (lymphocytes and plasma cells) with a small increase of its thickness. This reaction was observed only at 1 week postsurgery. At 4 and 12 weeks postsurgery, the spinal cord sections of the control rabbits were as normal as the spinal cord sections of the sham rabbits. For all the observation periods, the histologic analysis of the spinal cords of the sham rabbits showed normal spinal cord tissue with normal cells and dura mater, and also normal nerve roots.

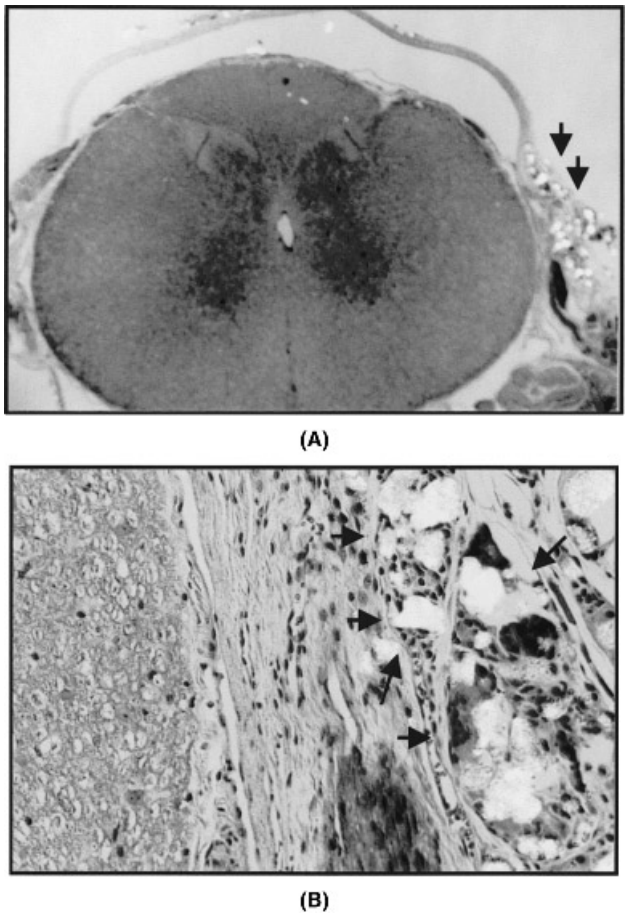

Figure 8. Polarized photomicrographs of a test rabbit, a thoracic section 4 weeks postsurgery. (A) A panoramic view of the section showing particles on the dura mater and a nerve root (arrows). (B) High magnification of a nerve root showing some inflammatory cells surrounding the particles within the connective tissue (arrows). (HPS stain, original magnification ×31 and ×312, respectively.)

One week postsurgery

One week after the PEEK injection into the spinal canal, sections from the injection site and the vicinity showed inflammatory cell infiltration around the particles, especially in the dura mater (Fig. 5). However, the reaction was limited to the dura mater, showing granulocytes and macrophages around the particles. The particles were trapped in loose connective tissue nearby the dura mater. The particle's adherence to loose connective tissue increased the thickness of the dura mater especially at the injection site. The sections from the control rabbits showed a very mild inflammatory reaction (lymphocytes and plasma cells) of the dura mater, which appeared thicker at the injection site (Fig. 6). For the test and control specimens, the spinal cord tissue did not develop any adverse reaction secondary to the saline or PEEK injections; all the nerve cells seemed as normal as within the sham sections (Fig. 7).

Four weeks postsurgery

Four weeks after the PEEK injection into the spinal canal, sections from the injection site and the vicinity showed some inflammatory cells (granulocytes, macrophages, giant cells) around the particles, which were still limited to the dura mater and the surrounding loose connective tissue. Therefore, no necrosis was observed either on the dura mater or on the nerve roots (Fig. 8). The spinal cord tissue did not develop any adverse reaction secondary to the PEEK injection; all the nerve cells seemed normal compared to the sham sections. Regarding the sections from the control rabbits, the mild inflammatory reaction and the dura mater thickness observed at 1 week postsurgery at the injection site were back to normal (Fig. 9) and they resembled the sham sections (Fig. 10).

Twelve weeks postsurgery

Twelve weeks after the PEEK injection into the spinal canal, sections from the injection site and the vicinity showed sparse inflammatory cells around the particles, which were still limited to the dura mater and the surrounding connective tissue. Therefore, no necrosis was observed either on the dura mater or on the nerve root. The spinal cord tissue did not develop any adverse reaction secondary to the PEEK injection;

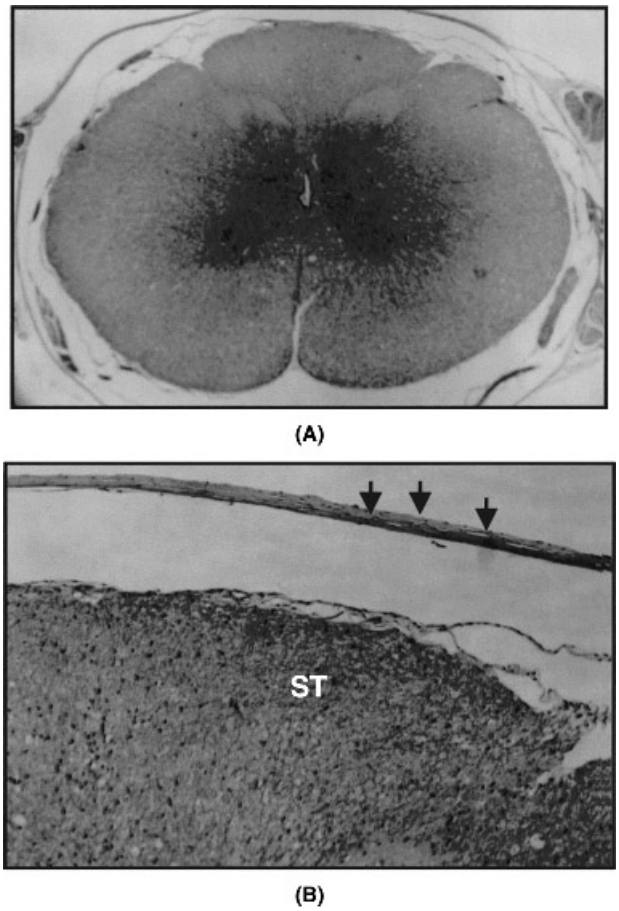

Figure 9. Light photomicrographs of a control rabbit, a thoracic section at the injection site. (A) Four weeks postsurgery. (B) High magnification of the dura mater shows a normal appearance of the nerve cells (spinal cord tissue, ST) and a normal dura mater (arrows). (HPS stain, original magnification ×31 and ×125, respectively.)

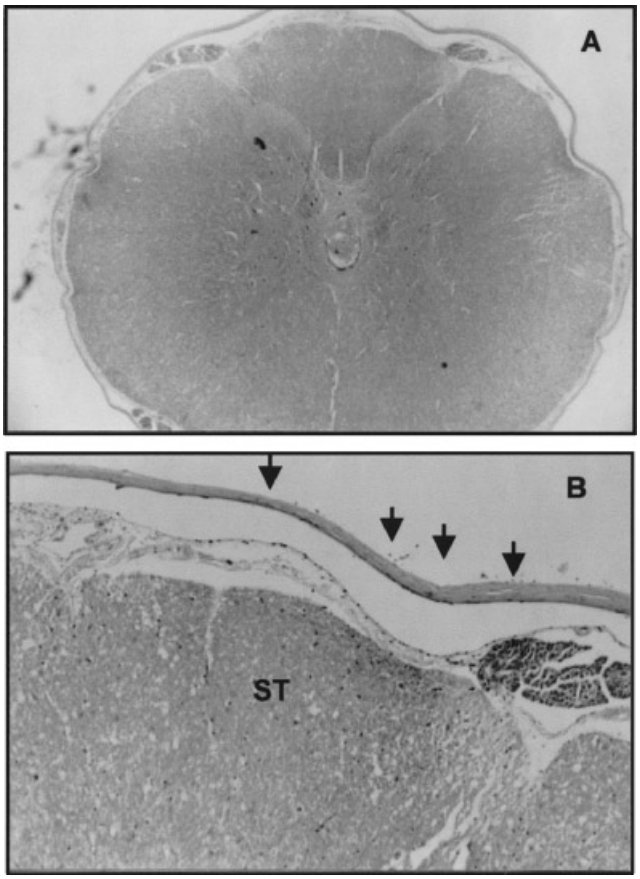

Figure 10. Light photomicrographs of a sham rabbit, a thoracic section. (A) Four weeks postsurgery. (B) High magnification of the dura mater shows a normal appearance of the nerve cells (spinal cord tissue, ST) and a normal dura mater (arrows). (HPS stain, original magnification ×31 and ×125, respectively.)

all the nerve cells seemed normal compared to the sham sections.

Inflammatory cell resorption was observed in the dura mater. A layer formed in the dura mater consisting of unphagocytosable particles sandwiched between the dura mater and the organized connective tissue, with collagen fibers running parallel to the particles (Fig. 11). However, the nerve cells did not show any adverse reaction to the adhered particles. Regarding the control sections, the spinal cord and dura mater tissues were the same as in the sham sections. The sections from the control and sham rabbits at 12 weeks postsurgery showed the same structures as the sections from the control and sham rabbits at 4 weeks postsurgery.

DISCUSSION

The evaluation of nervous tissue (spinal cord and nervous roots) compatibility to the PEEK material showed normal reactions of biological tissue to a foreign body.

At 1 week postsurgery, moderate inflammatory response of the dura mater was observed for all test specimens. The control specimens showed a very mild inflammatory reaction of the dura mater, which was demonstrated by its thickness especially at the injection sites.

However, at 4 weeks postsurgery, the inflammatory reaction of the dura mater became moderate to mild, with particles limited to the dura mater and the surrounding connective tissue. Regarding the control specimens, the dura mater showed normal appearance resembling the sham specimens.

At 12 weeks postsurgery, inflammation resorption was observed and the particles stayed limited to the dura mater. The unphagocytosable particles adhering to the dura mater were encapsulated by an organized fibrous connective tissue. Histologically during the observation periods (1, 4, and 12 weeks) the spinal cord tissue (nerve cells) did not develop any adverse reaction secondary to the particle injection.

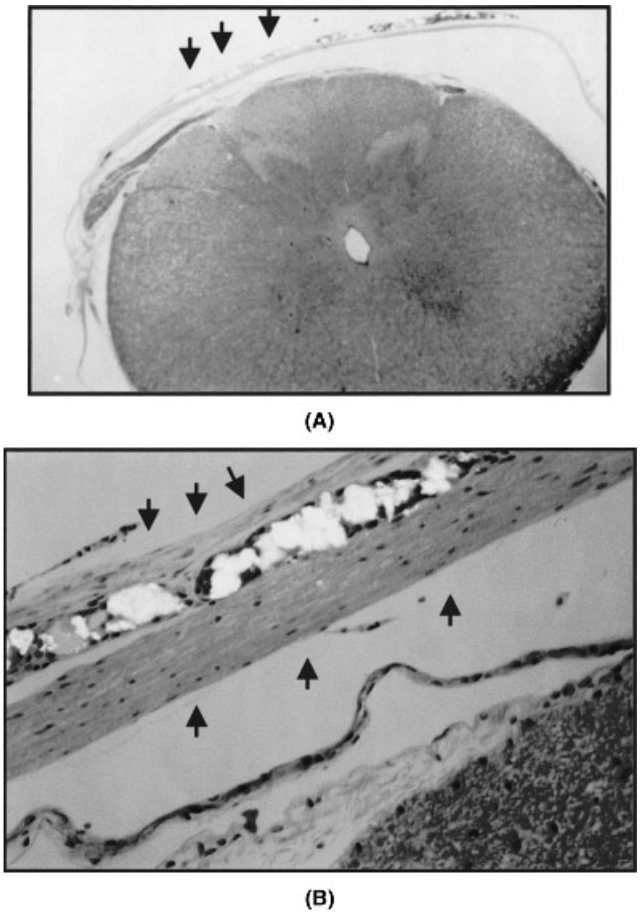

Figure 11. Polarized photomicrographs of a test rabbit, a thoracic section 12 weeks postsurgery. (A) A panoramic view of the section showing particles on the dura mater (arrows). (B) High magnification of the dura mater showing a layer of particles sandwiched between the dura mater and the organized connective tissue (arrows), with a significant resorption of the inflammatory cells. (HPS stain, original magnification ×31 and ×312, respectively.)

Macroscopically, the test specimens examined at 12 weeks postsurgery demonstrated an increase of the connective tissue thickness surrounding the spinal cord at the injection site and the vicinity compared to the test specimens at 1 and 4 weeks postsurgery. However, the connective tissue thickness may be explained by the histological results of the dura mater reaction to the unphagocytosable particles that were encapsulated with connective tissue. This encapsulation of the particles may increase the connective tissue thickness, and it appeared at 12 weeks postsurgery.

In this investigation we studied the worst case scenario (50 million particles/site) of the PEEK particles getting into the spinal canal and their adherence to the dura mater. Because our spinal implant system is designed to correct scoliosis without fusion, for this matter the surgical procedure for the spine clearance will be extra-periosteal and extra-spinal canal, which means the implant will therefore be surrounded by muscle and connective tissues. If there is any wear debris of PEEK production after a long period of implantation these particles will be limited to the adjacent tissue before crossing through the spinal canal by the ligamentum flavum. The ligamentum flavum will not be open with the ORTHOBIOM system, because we are not using laminar hooks.

In this subchronic study we demonstrated the excellent compatibility of the spinal cord and its nerve roots with PEEK particles. The spinal cord, dura mater, and nerve root tissues did not show any adverse reaction such as necrosis or chronic inflammation. The encapsulation of the particles is a normal reaction towards a compatible material. No animal mortality, paralysis, or any side effects related to the PEEK testing was experienced.

CONCLUSION

This study produced histopathologic evidence that the PEEK polymer was well tolerated by the nervous tissue (spinal cord, nerve roots, dura mater). The histological pattern of the dura mater to the PEEK suggests that this material is harmless to the spinal cord and nerve roots, and thus it might be used as component in the spinal implant.

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