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FROM THE DEPARTMENT OF SURGERY (DIRECTOR: PROF. N. OBEL), ROYAL VETERINARY COLLEGE, STOCKHOLM, SWEDEN

INFLUENCE OF EXTENSIVE LAMINECTOMY ON THE SHAPE OF THE SPINAL CANAL

BY

B. FUNKQUIST and B. SCHANTZ

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I. Laminectomy without Primary Narrowing of the Spinal Canal

INTRODUCTION

Although complications fully compatible with the suspicion of spinal cord compression have been observed during the course of healing after extensive laminectomy (von Colmar 1954, Bette 1955, Behrend 1957, Pouyanne 1957) no detailed experimental investigation into the effect of that operation on the shape and volume of the spinal canal has heretofore been reported. While studying the therapeutic value of decompressive laminectomy for herniated intervertebral disks in the thoraco-lumbar region in the dog, we made certain observations which suggested that the spinal canal following extensive laminectomy could be so narrowed as to occasion compression of the cord. We found these observations so interesting that we resolved upon an experimental study of this particular problem. Since the initial findings indicated that scar shrinkage of the granulation tissue bridging the surgical defect was a determinant factor in the spinal canal volume, the experimental conditions were varied, primarily with a view to preventing such shrinkage and its sequelae. Contracture of the surgically mobilized portions of the lumbodorsal fascia could not be excluded as a significant factor, and hence the experimental conditions were also varied with respect to the treatment of the fascia. The first section of this investigation (I) is concerned with the effect in dogs subjected to laminectomy alone (with or without the secondary measures defined under subheadings A1-A3). The second section (II) deals with the effect in dogs whose spinal canals were narrowed at the start of healing, by an epidural injection of paraffin, given either before or immediately after the laminectomy.

Experimental Techniques Common to both Groups of Experiments (A and B)

A total of 33 dogs ranging in age from 6 months to 2 years and in weight from 6 to 20 kg (mean 11 kg) were used for the experiments.

Anesthesia was induced by intravenous injection of Intraval® and maintained by a 4:1 mixture of nitrous oxide and oxygen. Muscle relaxation, when indicated, was produced by repeated intravenous injections of succinylcholine iodide

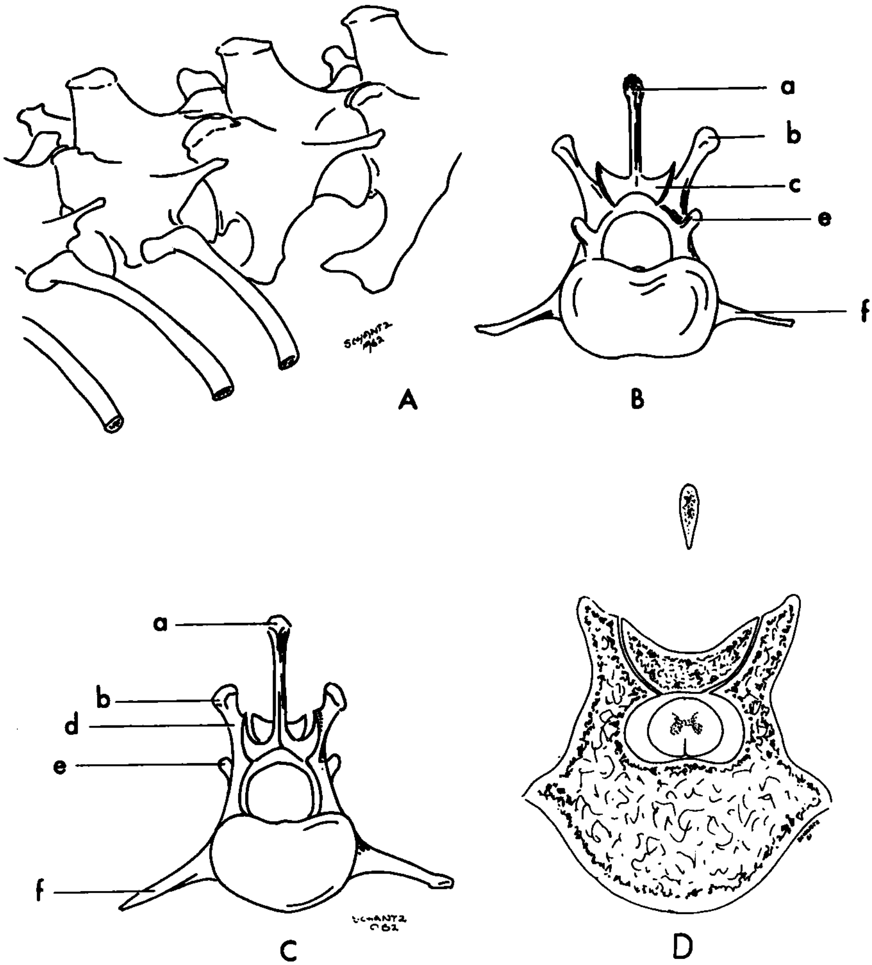


Fig. 1. The anatomy of the dog's vertebral column in the region of the experimental operations.

A) : The vertebral column of the dog viewed obliquely from above at the junction between the thoracic and lumbar regions.

B) : First lumbar vertebra ; posterior view.

C) : First lumbar vertebra ; anterior view. a) Spinous process. b) Mammillary process. c) Caudal (inner) articular process. d) Cranial (outer) articular process. e) Accessory process. f) Transverse process.

D) : Cross-section of the first lumbar vertebra close to the disk of T13/L1 with the spinal cord fixed *in situ*.

(Celocurin®) in doses of 0.5 mg per kg body weight (Hansson 1958). Artificial respiration, if needed during muscle relaxation, was given with the aid of a "pulmomat" (Dräger). The anatomy of the dog is such (fig. 1) that the present experimental surgery traumatized the spinal column, and especially the articular processes, to a much greater degree than would corresponding operative measures in humans. Following laminectomy the dogs were kept under observation for periods that will be indicated in the reports on the respective groups (usually, at least 3 months). During the first two months or so of the observation period roentgenologic examination (lateral projection) was carried out, as a rule, at intervals of approximately two weeks, and subsequently about every four weeks. Some time during the last week of observation (generally, a few days prior to sacrifice) the majority of the dogs were subjected to subarachnoid myelography with Kontrast U® with a technique which has been described elsewhere (Funkquist 1962).

At the end of observation the animals were sacrificed by rapid intravenous injection of Mebumal® in a dose of approximately 60 mg per kg body weight. Fixation was done immediately after death, by intra-arterial injection of 10 per cent formalin (dissolved in physiologic saline) with a previously described technique (Funkquist & Obel 1961). After about 24 hours' storage of the cadavers in a refrigerator the relevant portion of the vertebral column was isolated and the bulk of the adjacent soft tissues dissected away. The excised specimens were immersed in formalin for approximately one week, then frozen at ÷20°C for 2-3 days, after which they were sawn into sections about half the length of a vertebra. The sections were laid in the transverse plane—alternately through or in the vicinity of the disks, and through the midpart of the vertebral body. These transverse sections with the spinal cord *in situ* were inspected, in frozen condition, primarily with respect to the cross-sectional shape of the cord and the appearance of the tissue bridging the defect in the dorsal wall of the spinal canal (hereinafter called the defect). With the guidance of this preliminary inspection a number of representative specimens were selected, from which frozen microsections 50-75 μ thick were prepared *ad modum* Ullberg (1958). The microsections were stained by Mayer's hemalum and eosin method. Immediately after sectioning, the surface from which the microsections had been taken was photographed in frozen condition. In at least one animal from each group, a sample of the tissue which had bridged the defect was taken from one of the transverse sections from the middle of the operative field. Following decalcification with nitric acid the sample was embedded in paraffin, then sliced into sections approximately 6-7 μ thick and stained with hematoxylin and eosin.

Nomenclature

In some of the dogs the operation produced dorso-ventral flattening of the spinal cord as well as symptoms of motor loss. To facilitate classification of the experimental results the following grading of these two phenomena was employed.

Dorso-ventral Flattening of the Spinal Cord

The degree of flattening was determined in that transverse section which had shown the most conspicuous changes—usually a section from the middle of the operative field. Grading was based on the quotient of the vertical (V) and horizontal (H) axis of the cross-section of the spinal cord as follows:

Grade I. The transverse section exhibited distinct dorso-ventral flattening, V/H however, being equal to or greater than 0.60.

Grade II. V/H was less than 0.60 but equal to or greater than 0.45.

Grade III. V/H was less than 0.45 (lowest value recorded, 0.30).

Symptoms of Motor Loss

Grade I. Mild paresis of the hind legs. These dogs walked without difficulty but tended to drag the dorsal surface of the hind paws along the ground. When moving briskly their hind quarters sometimes fell over, particularly when the dogs made sharp turns.

Grade II. Moderate paresis of the hind legs. The dogs in this subgroup walked unsteadily and with great difficulty. It was difficult for them to advance the legs, and they frequently set the dorsal surface of the hind paws on the ground.

Grade III. Subtotal to total paralysis of the hind legs. Walking was impossible, though some of the dogs showed a certain degree of voluntary motor activity of the hind legs.

A. Laminectomy with Complete Removal of the Dorsal and Dorso-lateral Parts of the Arch, Including the Articular Processes

MATERIAL AND METHOD

In a total of 27 dogs the dorsal and dorso-lateral parts of the four arches in the region from T12 to L2 were excised by the following technique. The skin of that region was incised in the median line. The fascia was incised on each side of, and contiguous to, the spinous processes of T11 to L3. With the aid of scissors and a raspatory the muscles and periosteum were detached from the spinous processes as well as from the articular processes and the dorsal aspects of the arches. After removal of the spinous processes with bone-cutting forceps the articular processes and the dorsal arches were gouged away sufficiently to expose the dorsal surface of the spinal cord—generally, as far as a level between the dorsal tangent and the horizontal axis of the cross-section of the spinal cord. The experimental conditions in group A were, in other respects, varied as follows:

1. In seven dogs the operation was confined to laminectomy as described above. In four of them the incision in the lumbo-dorsal fascia was closed with continuous catgut no. 2 sutures and the skin incision with interrupted stainless wire sutures. In the remaining three the skin alone was sutured and the incision in the fascia left open. The observation time in this group was from 6 to 9 months for five dogs, 3 months for one, and 15 months for the seventh.

2. In six dogs the defect was filled with bone chips not exceeding 2 mm in diameter and having an average weight of approximately 5 mg (mean of 100). The chips were obtained by fragmenting with gouge forceps the excised parts of the arches. They were placed in two or three layers directly upon the dural surface between the cut surfaces of the arch. The fascial defect was sutured as above in three of these six animals and left open in the other three. Except for one dog with 4 months observation and another with $8^1/_2$ months, the observation time was 6-7 months.

3. The surface of the dura was, in five dogs, covered with a layer of subcutaneous fat fragments 2-4 mm in diameter, obtained from the operative region. Above this fat layer were placed bone chips as described above. The fascia was sutured in two of the five animals and left open in the other three. The observation time ranged from 5 to 7 months.

4. In nine animals a strip of sheet polyethylene 0.02 mm thick was so inserted

as to form a "septum" extending in the median plane throughout the surgical defect from the dura to the lumbodorsal fascia. Its ventral border was sutured with silk (5:0) to the dorsal surface of the dura along a median line. In three of the animals subcutaneous fat plus bone chips, and in another three bone chips alone, were placed on the dura (on both sides of the plastic strip) as described in paragraphs 2 and 3, above. The dorsal edge of the plastic strip was, in all dogs, sutured to one edge of the fascial incision. Aside from this measure the fascia was not sutured. The observation time was 4-5 months, except for two animals in which it was approximately 3 months.

RESULTS

A summary of the results is given in table I

Groups 1-3

Functional disturbances (motor loss and postural anomalies). – The seven dogs in which surgery had the character of laminectomy alone (group 1) tolerated the operation well; they exhibited no symptoms of motor loss during the first few weeks postoperatively. Paresis of the hind legs developed after some time in two cases (table 1). The initial symptoms appeared, in one of these two, 2 months after the operation; then developed over the course of 2-3 weeks into moderate paresis (grade II) which persisted for at further week, whereafter the dog was sacrificed. In the second case mild paresis (grade I) was first detected one month after the operation and persisted about one month. For the remainder of the observation period (4 months) the motor activity was normal.

Kyphosis (of relatively mild degree) was observed in three dogs (table 1). In two of them it was the sole symptom. The kyphosis persisted throughout the observation period in one of these two and was observed intermittently in the other. In the third dog which, one month after the operation, also presented symptoms of motor loss (described above), mild kyphosis was observed for the first 14 days postoperatively.

The eleven animals referable to groups (2 and 3) in which laminectomy was combined with transplantation of bone chips or of subcutaneous fat plus bone chips, tolerated the operation itself satisfactorily, but diverged somewhat from the abovementioned dogs in regard to the postoperative course. Thus in four of the eleven, paresis appeared in the first postoperative week. In one of these four, in which paresis developed to grade II over the course of 8 days, the fascial sutures were removed on the eighth postoperative day and the tissues between fascia and dura were opened by a longitudinal incision extending the full length

Table 1.

Influence of Laminectomy on the Shape and Function of the Spinal Cord.

(For grading of changes and symptoms, see page 10 under the heading of "Nomenclature").

Section Number in Text	Experimental Conditions	Total Number of Dogs	Postural Anomalies		Symptoms of Motor Loss during Healing a)				Onset of Motor Loss Symptoms				Shape of Cross-section of the Spinal cord			
			Kyphosis	Lordosis	No Symptoms	Symptoms of Grade:			1st week	2nd to 4th week	2nd month	3rd month	No dorso-ventral Flattening	Dorsoventral Flattening of Grade:		
						I	II	III						I	II	III
A 1	Laminectomy with total excision of dorsal and dorsolateral parts of arch															
	With suture of lumbodorsal fascia ...	4	2		3		1					1			1	3
	Without suture of lumbodorsal fascia .	3	1		2	1[b]					1[b]			2		1
A 2	Laminectomy according to 1. Transplantation of autogenous bone chips to the defect.															
	With suture of lumbodorsal fascia ...	3	2		1	2			2							3
	Without suture of lumbodorsal fascia .	3	3		2		1			1					1	2
A 3	Laminectomy according to 1. Covering of dorsal surface of dura with autogenous fat; thereafter transplantation of autogenous bone chips as in 2.															
	With suture of lumbodorsal fascia ...	2	2			1	1[d]		2					1[d]		1
	Without suture of lumbodorsal fascia .	3	3		3										1	2
A 4	Laminectomy as in 1. Median polyethylene strip in defect.															
	Without tissue transplantation	3			3								–[e]	–	–	–
	With transplantation of bone chips ...	3	1		3								–[e]	–	–	–
	With transplantation of subcutaneous fat fragments and bone chips	3	2		2			1[c]				1[c]	–[e]	–	–	–
B	Laminectomy with retention of dorsolateral portion of compact bone of arch.															
	With suture of lumbodorsal fascia ...	3			3								3			
	Without suture of lumbodorsal fascia .	3		1	3								3			

a) At maximum intensity. b) Transient. c) Onset of fistula in surgical scar after $2^1/_2$ months.
d) The fascial sutures removed on the eighth postoperative day. e) Not comparable to other groups; see text.

of the operative field. The movements of the hind legs were dramatically improved immediately after this measure. They became quite normal within 48 hours, and remained so for the rest of the observation period.–Of the remaining three paretic animals, which exhibited less severe symptoms (grade I), one showed a progressive improvement during the remainder of the observation period, one no change in the symptoms, and the third a gradual deterioration after about 3 months. A further one of these eleven dogs developed moderate paresis (grade II) somewhat later in the postoperative course–after approximately 2 weeks. Although this animal gradually improved, it still had mild paresis at the end of observation.

Kyphosis was observed in ten of the eleven dogs in group 2 and 3. It was most conspicuous in the five with motor loss, in which it was present for the greater part of the observation period. Variations in the degree of kyphosis were generally correlated to variations in the intensity of paretic symptoms. In the other five dogs, the kyphosis developed at varying intervals after the operation and was of short duration (as a rule, 1-2 weeks).

When the incidence of paresis in all of the above groups (18 dogs) is considered in relation to the treatment of the fascia at operation, it emerges that paresis during the *first postoperative week* occurred in four of the nine animals in which the fascia had been sutured, but in none of the nine where the fascia had been left open. Further, this early paresis was limited strictly to dogs which had been subjected to transplantation of either bone chips or subcutaneous fat plus bone chips. Paresis of later onset (2 weeks, 1 month and 2 months respectively after operation) was noted in three animals–two in the group without fascial suture and one in the group with fascial suture.

Roentgenologic changes. – Plain films (lateral projection) generally disclosed, in the dogs which had undergone laminectomy alone, no appreciable changes aside from the surgical defect in the spinal column (fig. 2) and, in certain animals, the aforementioned kyphosis which was also demonstrable on physical inspection. During the latter part of the observation period, however, some animals exhibited osteophytes, simulating articular processes, on those portions of the arches which adjoined the intervertebral disks.

When the operation had been supplemented by transplantation of bone chips or of subcutaneous fat plus bone chips, the contours of the chips were still discernible at the initial roentgen examinations. The "chips" progressively increased in size and decreased in number. Two to 4 months after the operation the grafts had coalesced, roentgenologically, into a bone plate, though in most instances it was interrupted above the disks (fig. 3).

Myelographic examination was undertaken in 18 animals. On lateral films

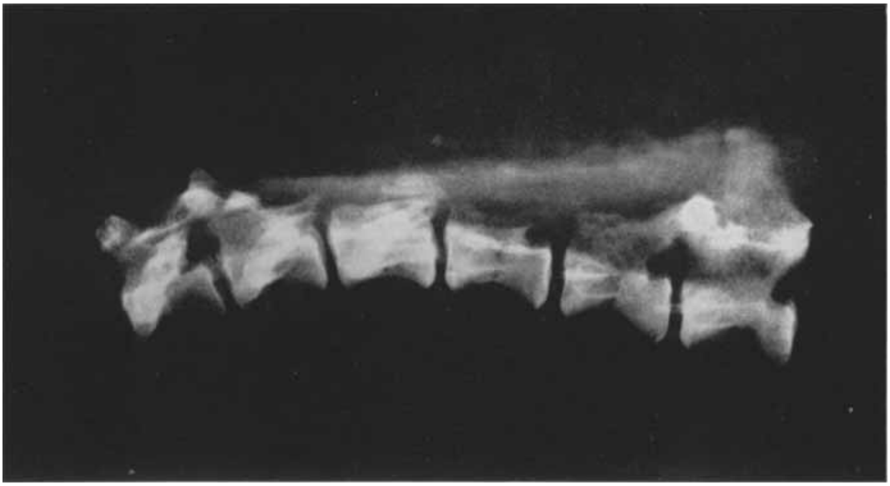


Fig. 2. Radiograph (lateral exposure) of a preparation of a dog's vertebral column from T11 to L3. The animal was killed approx. 6 months after laminectomy on T12-L2 according to A.
No remarkable changes except the surgically produced defect in the vertebral column.

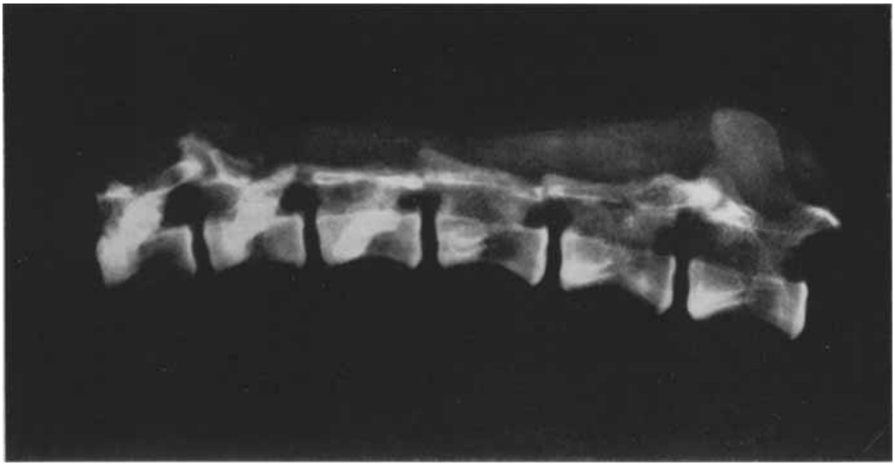


Fig. 3. Radiograph (lateral exposure) of a preparation of a dog's vertebral column from T11 to L3. The animal was killed approx. 7 months after laminectomy on T12-L2 according to A, combined with transplantation of autogenous bone chips to the defect in the roof.
The grafts have fused to a bony plate forming a new roof of the spinal canal with the exception of the parts situated just above the disks.

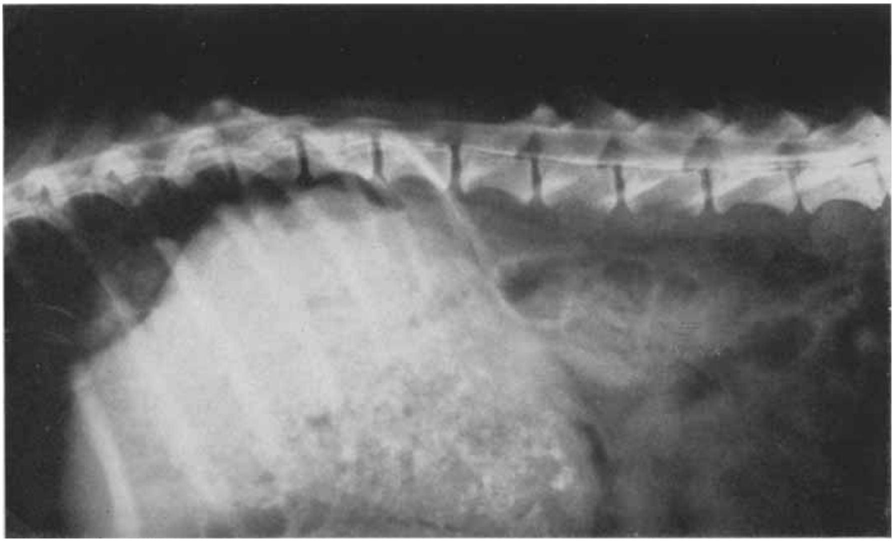
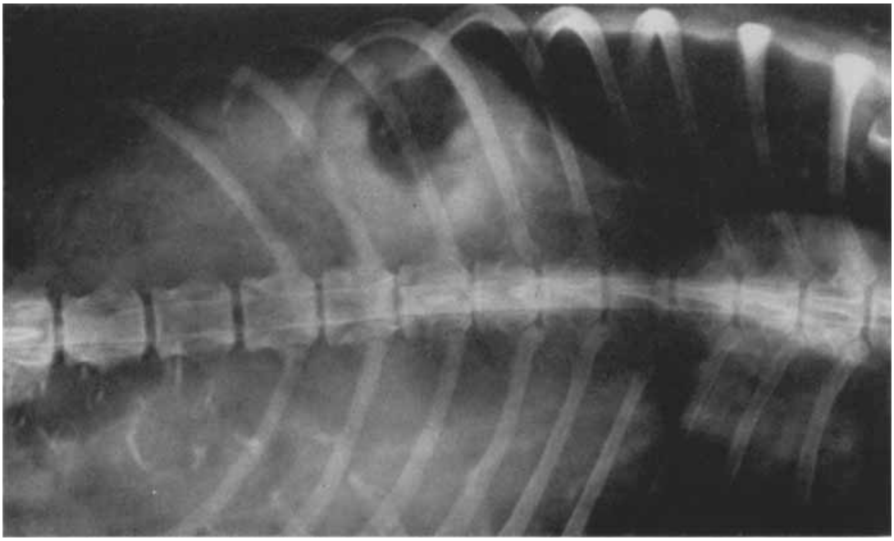


Fig. 4. Myelogram (lumbar subarachnoid injection with Kontrast U®) from an experimental dog 6 months after laminectomy on T12-L2 according to A.
a) : Lateral exposure. Dorsal impression in the contrast column within the middle part of the laminectomized area.



b) : Ventro-dorsal exposure. Broadening of the contrast column and a thinning of its lateral borders within the middle part of the laminectomized area.

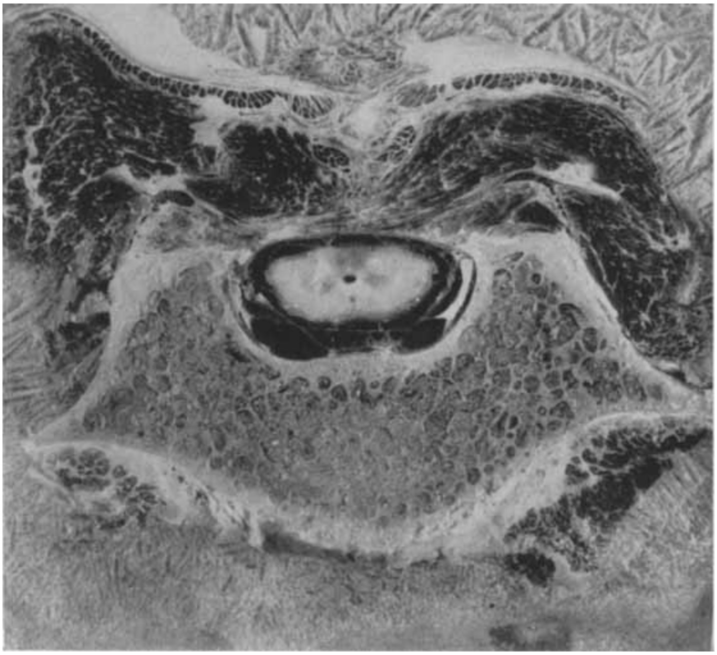


Fig. 5a. Cross-section through the middle part of L1. The animal was killed approx. 3 months after laminectomy on T12-L2, according to technique A.
The defect in the roof of the spinal canal is bridged by fibrous tissue which is attached to the fracture surfaces of the remaining portions of the arch. Severe dorso-ventral flattening of the spinal cord.

the observed myelographic changes appeared as filling defects in the dorsal subarachnoid space (fig. 4a), and on frontal views as a broadening of the contrast column (fig. 4b) and/or interruption of its borders. Myelographic changes were noted in 16 of the 18 dogs examined. In eight of them the changes were detectable on both lateral and frontal views; in five, on lateral views only, and in three on frontal views only. As regards the type and degree of these changes, no conspicuous differences were observed between the different groups. It should be noted, however, that both of the normal myelograms were referable to dogs which had been subjected neither to transplantation of tissue nor to suture of the fascia.

Patho-anatomic changes. – In those animals in which the operation had been confined to laminectomy without transplantation (group 1) the caudalmost and cranialmost parts of the defect (about half the length of a vertebra) were found to be bridged by osseous tissue. The rest of the defect was bridged with

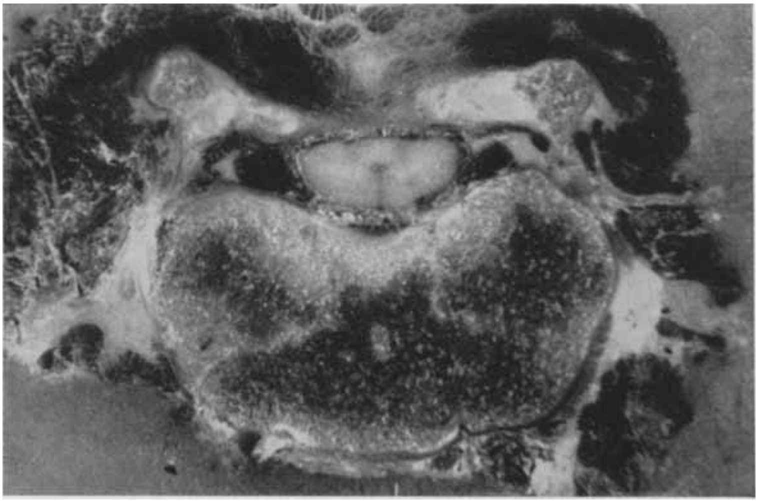


Fig. 5b. Cross-section close to the disk T13/L1 of the dog described in the legend to fig. 5a.
The defect is bridged by fibrous tissue situated at approximately the same level above the floor of the spinal canal as the corresponding tissue of the middle part of the vertebra (*cf.* fig. 5a). Severe dorso-ventral flattening of the cord. Bilateral osseous processes (remnants of the articular processes or newly formed bone originating from such remnants) project dorsally to a level considerably higher than the above mentioned connective tissue membrane.

fibrous tissue poor in cells. In cross-sections through the vertebrae situated near the middle of the operative field the lower border of this bridge of tissue largely coincided with a straight line between the upper edges of the remaining parts of the arch (fig. 5a). In cross-sections through or in the vicinity of the corresponding intervertebral disks the bridging fibrous tissue maintained the same level as in the middle of the vertebrae in spite of the fact that osseous processes emanating from the cranial or caudal ends of the vertebrae (remnants of articular processes or newformed bone; *cf.* roentgen findings) in some animals reached a higher level (fig. 5b). In the cranial and caudal portions of the defect the bridge of fibrous tissue rose gradually to normal level. The spinal cord in the middle of the region of laminectomy showed, in each of the animals in this group, dorso-ventral flattening of varying degree (fig. 5, table 1), though invariably most pronounced above the intervertebral disks. The deformation of the spinal cord was particularly marked in the dogs which had exhibited symptoms of motor loss.

When bone chips or subcutaneous fat plus bone chips had been transplanted in conjunction with the laminectomy (groups 2 and 3), the defects were usually bridged by osseous tissue over the midportions of the vertebrae. Above the disks, on the other hand, the bridge consisted of fibrous connective tissue in which ossified areas were interspersed. As in the group 1 animals, the ventral border of the tissue bridging the middle part of the defect was situated at the level of a line passing between the original cut surfaces of the arch. Cranially and caudally the bridge rose gradually to normal level. Dorso-ventral cord flattening of varying degree was noted, in all cases, in the central area of the operative field (fig. 6). It was greatest, as in group 1, above the intervertebral disks. With a single exception–the aforementioned animal in which the fascial sutures had been opened–all dogs that had suffered from motor loss exhibited a high degree of cord deformation (grade III). In the exceptional case the cord was only slightly flattened (grade I).

Group 4

Functional disturbances.–Each of the nine dogs in which a median polyethylene "septum" extending from the dura to the fascial incision had been inserted at operation, showed normal motor activity during the first months. One of

Fig. 6. Cross-section through the disk T12/T13. The animal was killed approx. 5 months after laminectomy on T12-L2 according to technique A, which was combined with a transplantation of autogenous fat and bone chips to the defect in the roof of the spinal canal.
The defect is bridged by a continous bone plate. There is a severe dorso-ventral flattening of the cord.

Fig. 7. Cross-section close to the disk T13/L1. The animal was killed approx. 4 months after laminectomy according to A. The operation has been combined with autogenous transplantation of fat and bone chips after a strip of polyethylene had been placed in the median plane from the dorsal surface of the dura to the edge of the fascia incision.
The defect in the roof is filled with fibrous connective tissue interspersed with ossified areas. Close to the median plane there is a vertical cleft extending down to the dorsal surface of the dura. Dorso-lateral flattening of the cord makes the cross-section appear almost in the shape of a triangle.

the animals in which the insertion of this "septum" had been combined with transplantation of subcutaneous fat as well as bone chips, suddenly developed subtotal paralysis (grade III) of the hind legs $2^1/_2$ months after the operation. The paralysis coincided with the onset of a fistula in the surgical scar and remained unchanged during the rest of the period of observation (7 days). The remaining dogs displayed no motor disturbances during the observation period. One animal had mild kyphosis throughout the observation period, and another showed transient moderate kyphosis during the first postoperative month. Lastly, the abovementioned dog with a fistula in the surgical scar had transient moderate kyphosis at the time of its onset.

Roentgenologic changes.—Plain films (lateral projection) revealed changes essentially identical to those described for the corresponding animals in groups A1-3. Myelographic examinition was carried out in seven of the nine dogs and disclosed, in six of them, dorsal filling defects of the character already described. The myelographic changes were located, as a rule, above the intervertebral disks in the central parts of the operative field. The seventh animal had a normal myelogram.

Patho-anatomic changes. — The tissue bridging the defect was, in principle, of the same type as the one described for the corresponding experiments in groups A1-3. All animals had, in or near the median plane, a cleft which usually extended through the bridging tissue to a point contiguous to the dura. In two animals, however, some part of the clefts—located in one animal at T13 and in the other at the twentieth intervertebral disk—terminated 2 mm and 5 mm respectively above the dura. Although spinal cord deformation was noted in all animals, it differed from that in the previously described groups inasmuch as the flattening was principally dorso-lateral, the cord frequently having a triangular cross section (fig. 7).

B. Laminectomy with Retention of the Outer Compact Bone of the Dorso-lateral Portion of the Arch

MATERIAL AND METHOD

Six dogs were subjected to laminectomy, likewise from T12 to L2 inclusive, with the following technique. The procedure for incision of the skin and fascia, excision of the spinous processes, and detachment of muscle and periosteum from the dorsal aspects of the arches was as described in section A. By means of a pneumatic dental drill a median groove a few millimetres wide was made in the dorsal surface of the arches throughout the area relevant to the laminectomy (fig. 8b and c). The turbine and hand-grip for operating the drill were of Atlas Copco make (50,000 r.p.m.). Round burrs with diametres varying from 1.1 to 2.9 mm were used. When the base of the groove had become so thin that it tended to sag under the burr, no further deepening was done, but excavation was continued in the lateral and latero-ventral directions (fig. 8d). The dorso-lateral portions of the arches were thus excavated by removal of the cancellous bone and the outer layers of the inner compact bone, while the outer compact bone was left intact. The outer (cranial) articular processes were largely undisturbed, but it was necessary to remove major portions of the inner (caudal) articular processes. Transection of the inner articular process

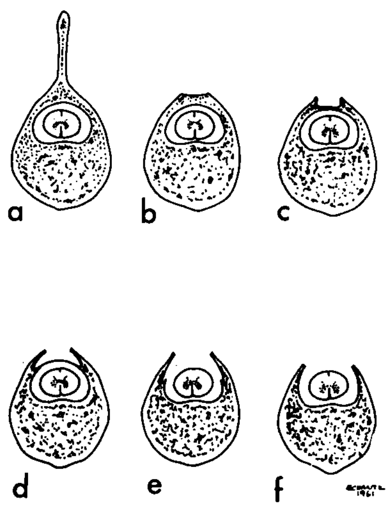


Fig. 8. Outline drawings of the technique of laminectomy with retention of the outer compact bone of the dorsolateral portion of the arch (technique B).

was sometimes required, particularly in small dogs, and in these cases the isolated tip of the process was removed. Excavation of the arches was continued as far ventrad as the anatomy permitted—usually as far as a plane situated approximately midway between the dorsal tangent and the horizontal diameter of the spinal canal. The thin persistent remnant of the inner compact bone of the arch was then removed with a small gouge forceps. In the lateralmost portion it was difficult to reach the inner compact bone with this instrument without disturbing the spinal cord; consequently, a sharp bony ridge usually remained when the gouging had been completed (fig. 8e). This ridge was removed with a small scoop. On termination of the above procedure all that remained of the dorsal wall of the spinal canal was a "shell" of outer compact bone in the dorso-lateral portion of the arch as well as the outer and, sometimes, parts of the inner articular processes (fig. 8f). In three of the animals the lumbodorsal fascia was sutured and in the other three it was left open. The skin in each case was sutured as described above. Except for one animal which was observed approximately 7 months, the observation time was 4-5 months.

RESULTS

A summary of the results is given in table I

Functional disturbances.—All dogs exhibited, when they had recovered from the anesthesia, normal motor activity until the end of the observation period (table 1). While no kyphosis was observed in this group, moderate lordosis occurred in one dog (in which the fascial incision had not been sutured).

Roentgenologic changes.—Plain films (lateral projection) revealed no changes of note aside from the surgical defect in the vertebral column (fig. 9). Three animals were subjected to myelography, and in two of them the contrast column on the frontal view was abnormally narrow (fig. 10). One of these two also presented a slight impression in the dorsal contrast line above the disk between T13 and L1. An impression of the last-mentioned type was noted as the only change in the third animal.

Patho-anatomic changes.—As in the previously described type of laminectomy, the defect was bridged by osseous tissue in its caudalmost and cranialmost parts. In some animals osseous bridges were found also on vertebrae situated more centrally in the region of laminectomy. The remainder of the defect was filled with fibrous tissue poor in cells. The cross-sections at the intervertebral disks showed in some animals, on the inside of the remaining parts of the articular

Fig. 9. Radiograph (lateral exposure) of a preparation (T11-L3) of the vertebral column of a dog. The animal was sacrificed approx. 5 months after laminectomy on T12-L2 according to B.
There are no remarkable radiological changes beyond the defect in the vertebral column produced by surgery (including removal of the inner articular processes).

processes, areas of new-formed bone with interpersed islands of cartilage. In no case was there any demonstrable dorso-ventral flattening of the cord such as that which followed type A laminectomy (fig. 11). One of the animals showed, however, in the central area of the operative field, a certain degree of lateral flattening, the vertical axis of the cross-section of the cord being equal to or somewhat greater than its horizontal axis (fig. 12). The vertebral sinus in the last-mentioned dog showed heavy filling (fig. 12).

DISCUSSION

In all dogs which had undergone laminectomy at the junction of the thoracic and lumbar regions, with complete removal of the dorsal and dorso-lateral parts of the arch as well as the articular processes (type A laminectomy), dorso-ventral flattening of the cord occurred during healing. It was possible to avoid this deformation of the cord, following laminectomy in the same area, by conserving the outer compact bone in the dorso-lateral part of the arch as well as the outer articular processes (type B laminectomy). By virtue of the special technique employed at the patho-anatomic examination, those spinal cord deformations which followed type A laminectomy could be attributed to the fact that the lower border of the fibrous tissue which bridged the postlaminec-

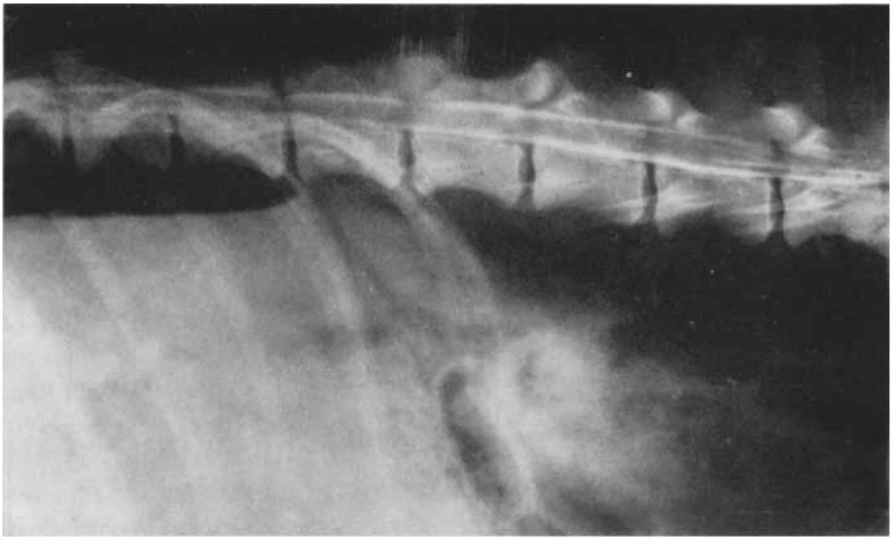
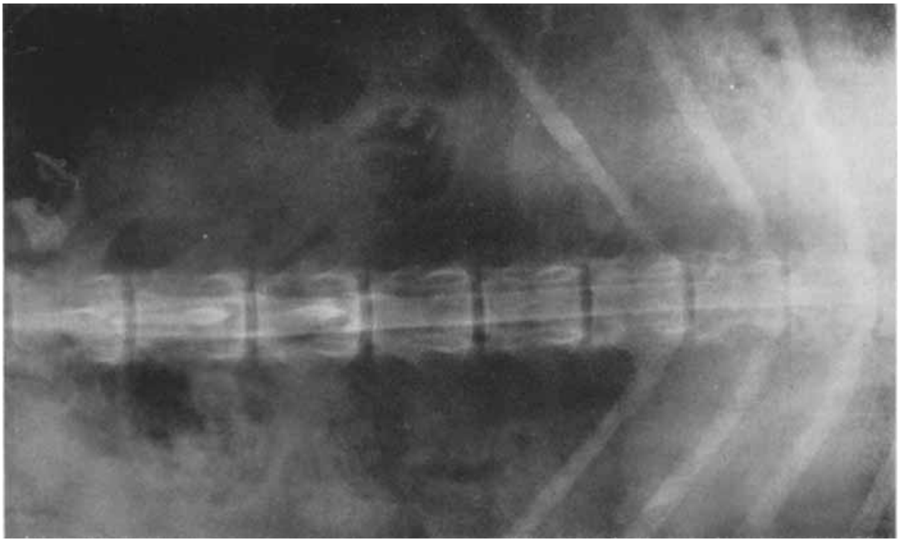


Fig. 10. Myelogram from an experimental dog approx. 4 months after laminectomy on T12-L2 according to B.
a) : Lateral exposure. Small dorsal impressions in the contrast column above the disks T13/L1 and L1/L2 (*cf.* Fig. 4a).



b) : Ventro-dorsal exposure. The contrast column is narrower than normally within the middle part of the laminectomized area.

tomy defect largely coincided with a straight line between the cut surfaces of the remaining parts of the arch.

The abovementioned variations in the shape of the cross-section of the cord following different types of laminectomy might be accounted for as follows. If the granulation tissue bridging the post-laminectomy defect is assumed to be fixed to both cut surfaces of the arch, it may form, on scar contracture, a tense membrane between those two attachments. Following type A laminectomy, at which the arch is excised down to a plane below the dorsal tangent of the cord, this membrane will then compress the cord against the base of the spinal canal. Following type B laminectomy, which conserves the dorso-lateral portion of the compact bone of the arch, the granulation tissue will have its attachments at a higher level and the membrane associated with scar contracture will form at a greater distance from the canal floor, thus precluding spinal cord compression.

This tentative explanation of the pathogenesis of post-laminectomy compression of the cord is supported by the observations referable to those dogs in

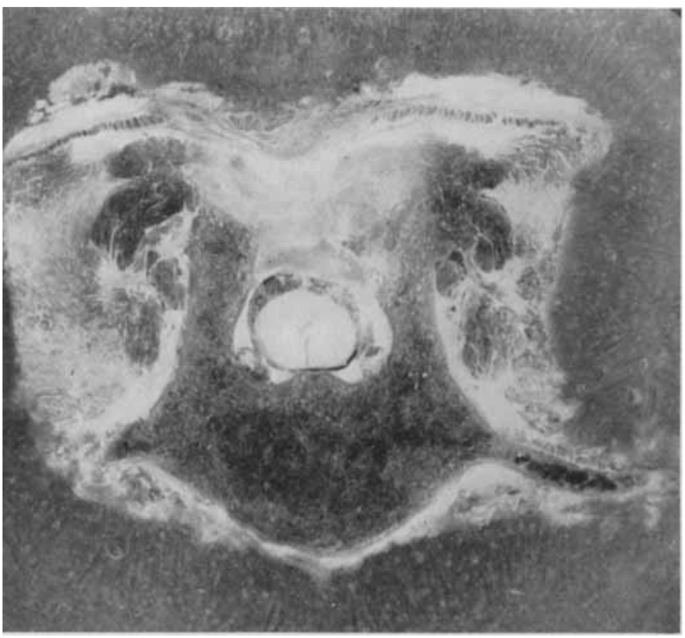


Fig. 11. Cross-section close to the disk T13/L1. The animal was destroyed approx. 7 months after laminectomy on T12-L2 according to B.
The defect in the roof of the spinal canal is filled with fibrous connective tissue. There is no obvious change of the shape of the cross-section of the spinal cord.

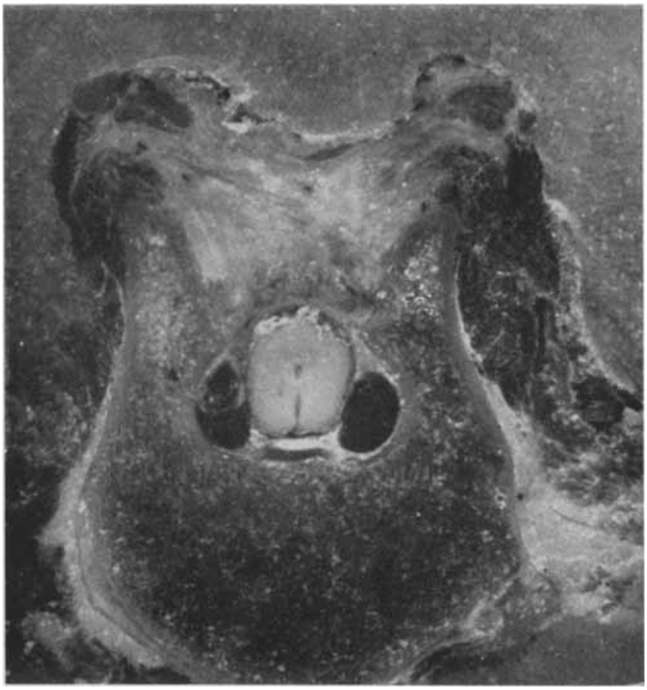


Fig. 12. Cross-section close to the disk T12/T13. The animal was killed approx. 5 months after laminectomy on T12-L2 according to B.
The cord is flattened laterally. The vertebral sinuses are well filled.

which, after laminectomy, the space between the cord and the fascial incision was divided by a median "septum" of polyethylene. The application of this plastic strip was designed to avert the effect of the transverse component of the scar contracture. Although appreciable deformation of the cord occurred even in these animals, the space available to the spinal cord seemed to be considerably greater in the vicinity of the median plane, so that the cord often assumed a triangular cross-section. Also worthy of note is the absence of motor loss in these dogs, with the exception of one in which a fistula opened in the surgical scar, thus showing that inflammatory changes had probably contributed to the genesis of the symptoms. The fact that a certain degree of compression arose even though the tissue covering the cord had been interrupted in the median plane, may well have been attributable to the longitudinal component of the shrinkage. Owing to the physiologic dorsal convexity of the vertebral column in the pertinent region, even the longitudinal shrinkage probably tends to compress the cord against the canal floor.

It is evident from the foregoing that of the operative methods tried, only that technique (B) which conserved the outer compact bone in the dorsolateral portion of the arch afforded an adequate safeguard against grave spinal cord compression following extensive laminectomy at the junction of the thoracic and lumbar segments of the vertebral column. Although slight lateral flattening was noted in one case after laminectomy of this type, it was not associated with neurologic symptoms. A probable explanation of the latter type of spinal cord deformation is that the scar shrinkage serves to raise the meninges —and with them the cord itself—towards the fibrous-tissue bridge which unites the tips of remaining parts of the arch. Proliferative processes on the damaged inner surface of the arch may, of course, have contributed to the deformation, but the presence of a distended venous sinus ventral to the cord (fig. 12) lends weight to the assumption that the lateral flattening is largely attributable to elevation of the dura.

Our attempts to reduce the tendency towards stricture of the spinal canal by transplanting autogenous bone chips in order to promote early ossification of the tissue bridging the defect, did not lead to the desired results. The same was true of the experiments designed to increase the diameter of the bony canal by clothing the dorsal surface of the dura with autogenous fat prior to the application of bone chips. The experiments may nevertheless be of some interest when considered in relation to the varied treatment of the lumbodorsal fascia. Paresis appearing within the first postoperative week and not attributable to the surgical trauma *per se* was observed only in cases where the fascia had been sutured in conjunction with transplantation of autogenous tissue. The dramatic improvement in the functional state of the spinal cord which, in one of these animals, followed opening of the fascial suture and underlying tissue down to the dura, suggests that an increase of pressure in that part of the surgical cavity which lies between the fascia and dura is a determinant factor in this early paresis. Since postoperative bleeding may well fill a volume equal to that occupied by the tissue grafts in these experiments, trials of therapeutic laminectomy with omission of the fascial sutures seem worth while. It is worthy of note that in our experimental animals the relatively large wound cavity which is inevitable if the operation is performed in the latter way did not entail any serious disadvantages in regard to wound healing.

As regards the incidence of kyphosis during the postoperative course there is a substantial difference between the two operative methods, kyphosis having arisen only after type A laminectomy, at which the dorsal portion of the arch as well as the articular processes were excised. The cause of the difference may be that the animals, having lost the supportive action of the articular processes, were compelled to hold their backs in a kyphotic posture to counteract the effect of gravity. It is nevertheless conceivable that the spinal canal stricture was a contributory factor; for the cross-sectional area of the cord, as demonstrated by Breig (1960), is reduced on bending of the spinal column. Possibly, therefore, the animals assumed a kyphotic posture to lessen the pain which could well have resulted from compression of the cord and the nerve roots by the walls of the narrowed spinal canal.

SUMMARY

The healing process following thoraco-lumbar laminectomy comprising several vertebrae in dogs entails a risk of dorso-ventral compression of the spinal cord when the arch, including the articular processes, is excised down to a horizontal line bisecting the spinal cord. The compression is apparently due to the fact that the granulation tissue which bridges the dorsal defect in the spinal canal tends, on scar shrinkage, to follow a straight line between the cut surfaces of the remaining parts of the arch, thereby pressing the cord against the base of the spinal canal. Following laminectomy which conserves the outer portions of the arch, including the outer articular processes, dorso-ventral compression of the cord may be avoided–apparently because the scar tissue in this case will be attached to points well above the base of the spinal canal.

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II. Laminectomy in Connection with Primary Experimental Narrowing of the Spinal Canal

INTRODUCTION

The influence of extensive laminectomy on the shape of the spinal canal in healthy experimental dogs has been reported in an earlier paper (Part I). The results show that laminectomy in the region from T12 to L2 with complete removal of the dorsal and dorso-lateral parts of the vertebral arch including the articular processes down to a level below the dorsal tangent of the spinal cord (the A technique according to Part I) involves a major risk of dorso-ventral compression of the cord during healing. On the other hand, if the outer compact bone of the dorso-lateral parts of the arch including the outer articular processes are spared at laminectomy (the B technique), the abovementioned late complication can be prevented. In order to investigate how the process of healing after extensive laminectomy affected the spinal cord when the latter had been displaced in the dorsal direction—as may occur, for instance, in the case of a median herniated disk—the following experiments were carried out.

Experimental Techniques Common to both Groups of Experiments (A and B)

A total of 22 dogs ranging in age from 6 months to 2 years and in weight from 8 to 15 kg (mean 11.5 kg) were used for the experiments. Experimental conditions with regard to anesthesia and artificial respiration were the same as those described in Part I. Anesthesia was not combined with muscle relaxation in those experiments where transvertebral injections of paraffin were given.

After laminectomy the animals were observed for a period specified below in connection with the reports on the different experimental groups. At the end of the observation period the dogs were sacrificed and subjected to fixation by means of intra-arterial injections of formalin according to the method described in Part I. Patho-anatomic examination of the operative region was carried out with technique also described in Part I.

It was sought to elevate the spinal cord by introducing a paraffin mass into the ventral epidural space with one or the other of the following two methods.

Transvertebral Injection of Paraffin Wax

An extensive thoracotomy was performed in the eighth intercostal space on the left side. The incision through the soft parts was extended ventrally over the median plane whereby the eighth sternebra became accessible from the ventral side. In order to widen the opening in the thorax, the seventh and eighth ribs with the intercostal muscle tissue were cut at the costochondral junction. The ventral side of T10 and the adjoining parts of T9 and T11 were exposed by blunt dissection after double ligation and division of the relevant intercostal vessels. In the caudal part of T10 a shallow excavation was made by means of a small gouge in the median ridge situated on the ventral surface of the vertebra. From this excavation a channel was bored through the main part of the body of the vertebra by means of a stainless steel pin. The pin, the tip of which had been ground to a triangular pyramid, had a length of 40 cm and a diameter of 3 mm. In order to ensure as far as possible that the bored channel would be located in the median plane, the sternum was used as a directional device for the pin. Thus, on inserting the pin into the thoracic cavity it was first passed through the eighth sternebra in the manner illustrated in fig. 1. The channel bored through the sternum and the vertebra was progressively widened by replacing the 3 mm pin with pins of respectively 4, 5, and 6 mm in diameter. All pins were provided with adjustable stop rings (fig. 1) which were set with respect to the vertical diameter of the body of the vertebra according to the roentgenograms. Finally the bored channel was extended into the spinal canal by means of a 6 mm pin with a chisel-shaped tip. Since the bored channel had not formed a right angle to the spinal column but was directed obliquely

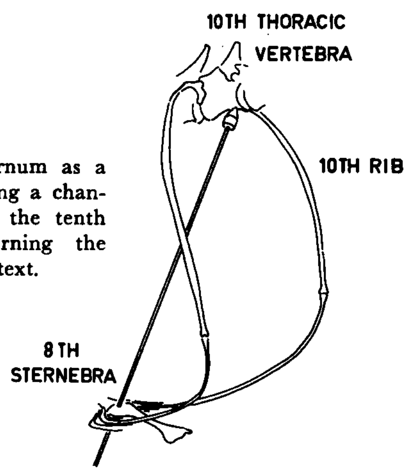

Fig 1. The use of the sternum as a directional device for boring a channel through the body of the tenth thoracic vertebra. Concerning the details please refer to the text.

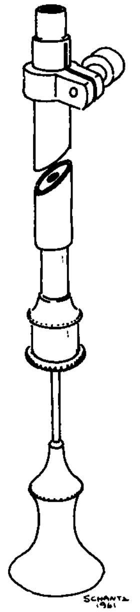

Fig. 2a.

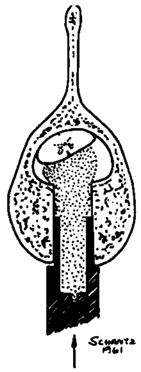

Fig. 2b.

Fig. 2. Elevation of the spinal cord by transvertebral injection of paraffin wax.
a) The trocar (fitted with outer tube and stop ring) for the injection of paraffin. Concerning the details please refer to the text.
b) The instrument inserted in the channel through the body of the vertebra during the injection into the spinal canal, of paraffin wax heated to a salve-like consistency.

caudalward, the chisel edge was bevelled to a corresponding angle so that the inner aperture should also encompass the caudal parts of the bored channel. The stop ring of the chisel-shaped pin was repeatedly reset until it could be ascertained by probing that the entire circumference of the bored channel had reached the spinal canal. During the last stage of the procedure the boring was carried out with small oscillatory movements of the pin whereby it was continuously checked that the acute angle of the edge was directed caudalward. A trocar was used to introduce paraffin into the spinal canal (fig. 2a). The trocar cannula had a caliber of 1.5 mm, an outer diameter of 4.9 mm and a length of approximately 80 mm. It was mounted for connection of an ordinary "Record" hypodermic syringe. The trocar was inserted into an outer tube (fig. 2a) with a caliber of 5 mm and an outer diameter of 6 mm. The length of the outer tube was so adjusted that the orifice of the trocar cannula fell about 10 mm short of the orifice of the outer tube when the trocar was completely inserted. The outer tube was fitted with an adjustable stop ring which, with the guidance of the roentgenogram, was so adjusted that the mouth of the outer tube was positioned a few millimetres ventral to the opening of the bored channel in the spinal canal when the stop ring was in contact with ventral surface of the vertebra. Prior to insertion of the assembled instrument into the bored channel, the trocar and that part of the outer tube in front of the orifice of the trocar cannula were filled, by a syringe, with melted paraffin ("Merck", melting point 56°-58° C) at a temperature of approximately 80° C. When the paraffin had cooled to a salve-like consistency, the instrument was inserted so far into the spinal canal that the stop ring came into contact with the ventral surface of the vertebra. The paraffin in the trocar cannula (approximately 0.1 ml) was thereafter pressed into the outer tube with the mandrin. A 1 ml tuberculin syringe was then used to inject 0.1 ml paraffin at about 80° C into the trocar. After cooling for about 10 seconds in the trocar cannula this paraffin was pressed into the outer tube with the mandrin. This procedure was repeated until the desired effect was obtained. As shown in fig. 2b, the injected paraffin is successively pressed into the spinal canal in the form of a "column" of semi-solid consistency. Where this transvertebral injection was given *before laminectomy* the introduction of paraffin was, as a rule, continued until the animal reacted with distinct (transient) spasm of the hind legs. On the basis of preliminary experiments on cadavers, however, the maximum dose was limited to 0.6-0.9 ml depending on the size of the animal, and at this dose the injections were discontinued even if no spasm had occurred. Where the paraffin injection was given *after laminectomy* the introduction of paraffin was continued until the spinal cord showed a distinct dorsal bulge. After completion of the paraffin injection, the apparatus was cooled for a few minutes with gauze soaked in physiological saline solution at room temperature. The apparatus was then removed. The thorax was closed with chromic catgut no. 2 sutures and the skin with stainless 0.21 mm wire sutures.

Introduction of Paraffin Wax into the Spinal Canal via the Laminectomy Opening

Laminectomy was performed on T12, T13, L1 and L2 with one of the two methods described below. A plastic tube was made by welding the edges of sheet polyethylene, 0.02 mm thick; the tube had a caliber of approximately 5 mm and a length of about 15 mm. One end of this tube was ligated with 3:0 silk a few millimetres from the opening, and at the other (free) end a suture (of the same material) with long ends was inserted. By means of doubled 0.5 mm wire the bent end of which was twisted into a loop, the ends of the suture were inserted under the spinal cord at the level of the disk between T13 and L1, between the relevant nerve roots, at an angle of approximately 45 degrees to the median plane. By gently pulling the suture the polyethylene tube was drawn so far under the cord that the aforementioned ligature reached the base of the spinal canal lateral to the cord. After removal of the suture, a probe-

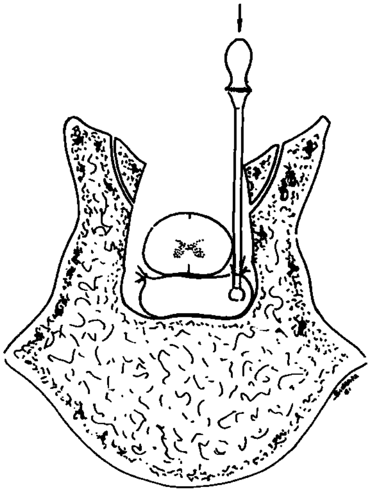

Fig. 3. Elevation of the spinal cord and its meninges by injection (via the laminectomy opening) of paraffin wax into a polyethylene tube, which is placed in the epidural space ventrally to the dura.

pointed cannula was inserted so far into the free end of the tube that its bulb-tip was positioned at the base of the spinal canal lateral to the spinal cord at the opposite side to the ligature. In this position it was fixed with a ligature drawn tightly around the polyethylene tube and the cannula just above the bulb-tip of the latter (fig. 3). Paraffin was then injected into the polyethylene tube as described earlier. The paraffin was injected at a temperature of about 80° C into the cannula in doses of 0.1 ml, was allowed to cool for about 10 seconds and was then pressed in semi-solid condition into the polyethylene tube by a mandrin fitted into the cannula. The procedure was repeated until the spinal cord showed a distinct dorsal bulge. The requisite dose varied from 0.25 ml to 0.30 ml. After the paraffin had cooled for about 5 minutes, the ligatures were removed and the polyethylene tube was fixed with a catgut suture (3:0 catgut) on each side to the musculature contiguous to the spinal column. The parts of the polyethylene tube outside the catgut sutures were thereafter cut off.

A. Laminectomy with Complete Removal of the Dorsal and Dorso-lateral Parts of the Arch, Including the Articular Processes

MATERIAL AND METHOD

Laminectomy was performed on a total of 11 dogs with the technique described in Part I, section A. The lumbodorsal fascia was not sutured. Prior to, or in connection with the operation, narrowing of the spinal canal was experimentally induced by one of the methods described above. The experimental conditions *within group A* were thus varied as follows.

1. Transvertebral paraffin injections at T10 were given in four dogs. When the animals had recovered 8 to 15 days after the first operation, laminectomy on T9 to T12 was performed. The paraffin was not removed at operation. The observation period was approximately 10 weeks as from the date of laminectomy.
2. Laminectomy on T9 to T12 was performed in four dogs. Before the wound was closed, a transvertebral paraffin injection was given at T10 with the previously described technique. The observation period was approximately 10 weeks.
3. Laminectomy on T12 to L2 was performed in three dogs. Prior to closure of the wound an epidural paraffin injection over the disk between T13 and L1 was given via the laminectomy opening with the technique described earlier. The observation period was four to five weeks.

RESULTS

A summary of the results is given in table I.

With regard to the nomenclature used for the evaluation of symptoms of motor loss and degree of spinal cord compression, see Part I, page 10, under the subheading of "Nomenclature".

Functional disturbances. – The postoperative course was as follows in the four animals, described under the subheading of 1, that had received paraffin injections in the spinal canal at T10 level and in which laminectomy was performed 8 to 15 days later on T9 to T12 with complete removal of the dorsal and

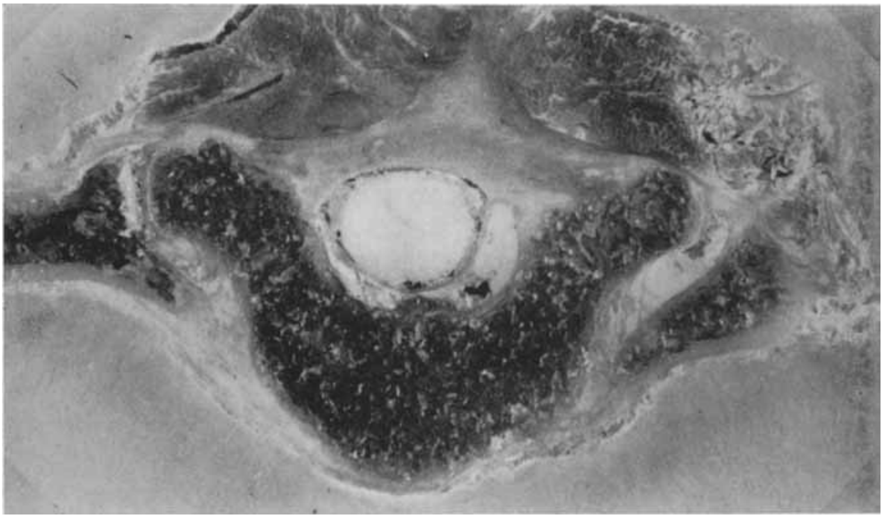

Fig. 4. Cross-section through T10 close to the disk T9/T10. The dog was killed about 10 weeks after laminectomy on T9-T12 according to technique A.
The defect in the roof of the spinal canal is bridged by a membrane of fibrous connective tissue, which is fixed to the dorsal surface of the costal attachments or to the transverse processes, i.e. to points, which are situated rather high above the floor of the spinal canal. No notable decrease of the vertical diameter of the canal.

dorso-lateral parts of the arches. Following the paraffin injection, symptoms of motor loss, varying from moderate paresis to subtotal or total paralysis were present (grade II in one animal, and grade III in three animals, one of which had spastic paralysis). The motor function gradually improved during the period prior to laminectomy. At the time of operation one dog had mild paresis (I), two moderate paresis (II), and one paralysis (III). In one of the animals laminectomy did not affect the motor function. In two of the dogs the operation caused a slight exacerbation of a few days' duration. In one case the existing paresis increased from grade II to grade III. The exacerbation had a duration of approximately three weeks. In this case wound infection with heavy suppuration occurred postoperatively. Otherwise all the dogs showed gradual progressive improvement after the operation. At the end of observation all the dogs were able to walk; three had mild paresis (grade I). The fourth dog, in which spastic paralysis was present after the paraffin injection, had grade II paresis at the end of the observation period.

Of the four animals, described under the subheading of 2, that had received a transvertebral paraffin injection at T10 after excision of the dorsal and dorsolateral parts of the arches in the region T9 to T12 (with technique A), three

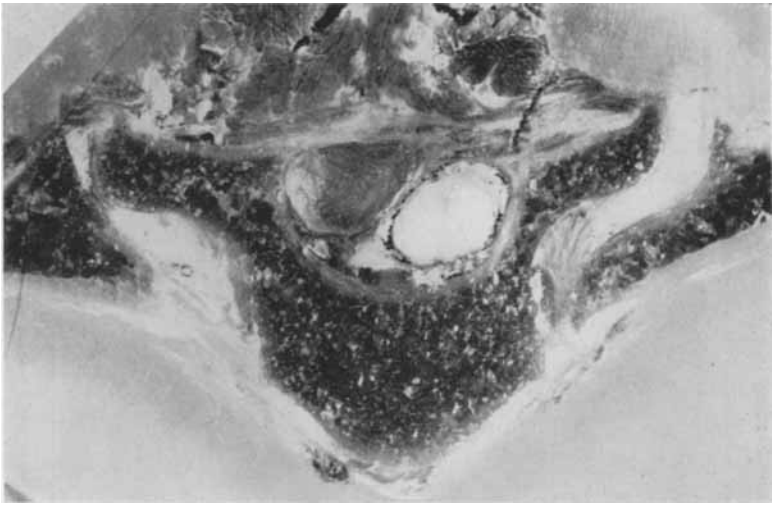

Fig. 5. Cross-section through T10. Transvertebral injection of paraffin wax. Laminectomy on T9-T12 according to technique A. Symptoms of motor loss, which followed the parraffin injection (grade II) gradually improved during the period prior to laminectomy. This caused a slight exacerbation of a short duration. After this the symptoms gradually improved until the end of the observation period (grade I). The animal was destroyed about 10 weeks after the laminectomy.
The defect is bridged by a membrane of fibrous connective tissue, which is fixed to the dorsal surface of the transverse processes. To the left there is a paraffin mass displacing the cord to the right and causing a dorsal-lateral impression of the cord's cross-section.

showed a largely normal motor function when they had recovered from the anesthesia. The condition of these dogs remained unchanged throughout the observation period. The fourth dog had, postoperatively, moderate paresis (grade II) which gradually subsided to mild paresis (grade I) during the observation period.

Of the three dogs, described under the subheading of 3, where laminectomy had been performed on T12 to L2 and where paraffin had been introduced into the ventral epidural space via the incision made at laminectomy, one showed mild and another moderate paresis (grade I and grade II respectively), while the third animal had a normal motor function. The former two dogs showed a gradual motor improvement during the fortnight following the operation. Approximately two weeks after the operation all three dogs had incipient motor impairment of the hind legs which gradually increased during the observation period. At the time of sacrifice two of the animals had spastic paralysis (grade III) and the third subtotal paralysis (grade III) with some remaining voluntary motor function.

Table 1.

Influence of Laminectomy in Animals with Experimental Narrowing of the Spinal Canal.

(For grading of changes and symptoms, see part I page 10 under the heading of "Nomenclature").

Section Number in Text	Experimental Conditions	Total Number of Dogs	Condition after Laminectomy				Condition at End of Observation				Shape of Cross-section of the Spinal cord			
			Normal Motor Activity	Symptoms of Motor Loss of Grade			Normal Motor Activity	Symptoms of Motor Loss of Grade			No dorso-ventral Flattening	Dorsoventral Flattening of Grade:		
				I	II	III		I	II	III		I	II	III
A 1	Transvertebral paraffin injection at T10. Type A laminectomy of T9-T12, 8 to 15 days after injection	4		1	1	2		3	1		–[a]	–	–	–
A 2	Type A laminectomy of T9-T12 with transvertebral paraffin injection at T10	4	3		1		3	1			–[b]	–	2	–
A 3	Type A laminectomy of T12-L2 with paraffin injection over T13/L1 via the laminectomy opening	3	1	1	1					3				3
B 1	Transvertebral paraffin injection at T10. Type B laminectomy of T9-T12, 9 to 17 days thereafter ...	4	1		2	1	1	3			–[a]	–	–	–
B 2	Type B laminectomy of T9-T12 with transvertebral paraffin injection at T10	4	2		1	1	3	1			3[b]	–	–	–
B 3	Type B laminectomy of T12-L2 with paraffin injection over T13/L1 via the laminectomy opening	3	1		2		2	1			3			

a) In the animals in these groups the dorso-ventral flattening of the spinal cord could not be graded owing to deformation caused by the lateral position of the paraffin.

b) In two animals (A2) and one animal (B2) respectively grading could not be done for reasons mentioned under "a".

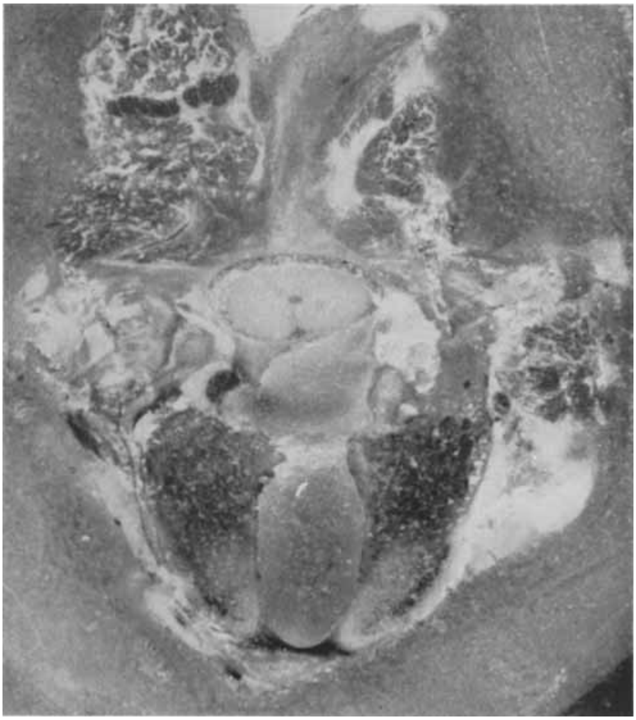

Fig. 6. Cross-section close to the disk T10/T11. Laminectomy on T9-T12 according to technique A with simultaneous elevation of the spinal cord by means of a transvertebral injection of paraffin wax. The symptoms of motor loss (grade II) exhibited by the animal on awakening gradually diminished, and persisted at the end of the observation time only as a slight paresis (grade I). The animal was killed about 10 weeks after the laminectomy.
The defect in the roof of the spinal canal is bridged by a membrane of fibrous connective tissue, which is fixed to the dorsal surface of the transverse processes. The spinal cord and its meninges are elevated by a ventral paraffin mass to such a degree that the distance between the ventral surface of the dura and the bottom of the canal is about one normal cord diameter. Moderate (grade II) dorso-ventral flattening of the cord.

Patho-anatomic changes.—Postoperative behaviour of the spinal column was similar to that described under A in Part I. The cranialmost and caudalmost parts of the defect made by laminectomy (approximately one half the length of the vertebra) were thus bridged by bone, while the remainder was filled with fibrous tissue with few cells. In those animals, described under the subheadings of 1 and 2, in which the operation was performed within the region of T9 and T12, this tissue membrane, which seemed to a large extent to be fixed to the dorsal surface of the costal attachments or to the transverse processes (fig. 4), was situated at a greater distance from the base of the spinal canal

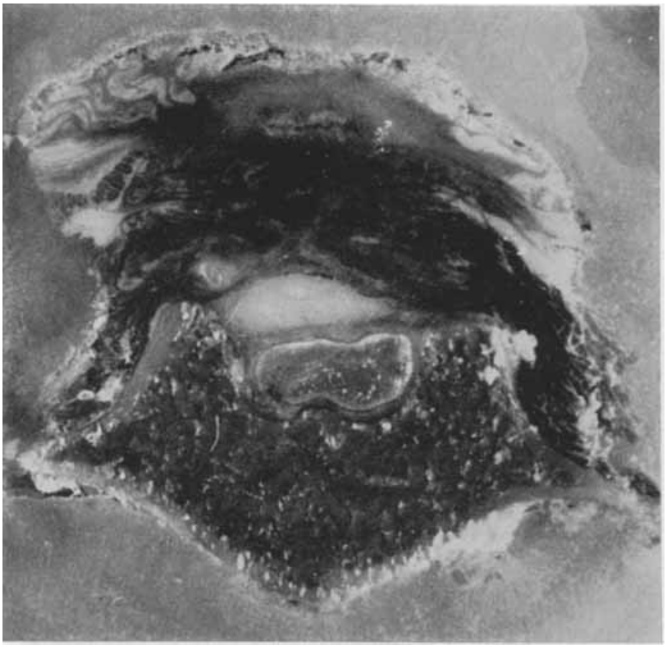

Fig. 7. Cross-section through the middle part of L1. Laminectomy on T12-L2 according to technique A with simultaneous elevation of the cord by injection (via the laminectomy opening) of paraffin wax into a polyethylene tube, which was placed in the epidural space ventrally to the dura. After awakening from the anaesthesia the animal's movements were almost normal. About 2 weeks after the operation symptoms of motor loss appeared and these further developed in another two weeks to a spastic paralysis (grade III). The animal was killed 5 weeks after the laminectomy.
The defect in the roof of the spinal canal is bridged by fibrous connective tissue. The cord and its meninges is elevated by a ventral paraffin mass to such an extent that the distance between the ventral surface of the dura and the floor of the spinal canal approximately corresponds to $^3/_4$ of a normal cord diameter. Severe (grade III) dorso-ventral flattening of the cord.

than was the case in dogs in which the laminectomies had been performed with the same technique at the thoraco-lumbar junction (see Part I). Accordingly, the tendency towards spinal cord compression—provided the effect of the paraffin is disregarded—was appreciably less than that after the abovementioned thoraco-lumbar laminectomies performed with the same technique. In the animals described under the subheading of 3 in which the operation was performed in the region of T12 to L2, the postoperative behaviour of the laminectomized vertebrae was fully consistent with that observed after corresponding experiments of type A in Part I; i.e., the space available to the spinal cord was substantially reduced in the vertical plane.

In those experiments where transvertebral paraffin injections were given (groups 1 and 2), the injected paraffin in the majority of cases passed to the side of the spinal cord, which was displaced in the lateral or dorso-lateral direction, and as a rule showed an impression corresponding to the paraffin (fig. 5). Only in two animals (both in group 2) did the bulk of the paraffin remain on the ventral aspect of the cord, thereby elevating it approximately one normal spinal cord diameter. In both of these cases moderate dorso-ventral compression of the cord (grade II) was present (fig. 6). In the group of three dogs described under the subheading of 3 where the paraffin had been introduced via the laminectomy opening, it invariably lay ventral to the cord and elevated the latter from one-half to one normal cord diameter. The spinal cord showed pronounced dorso-ventral compression (grade III) in all three animals (fig. 7).

B. Laminectomy with Retention of the Outer Compact Bone of the Dorso-lateral Portion of the Arch

MATERIAL AND METHOD

Laminectomy was performed on a total of 11 dogs with the technique described in Part I under B. The lumbodorsal fascia was not sutured in these experiments. Prior to or at laminectomy, experimental narrowing of the spinal canal was induced with one of the methods described earlier. The experimental conditions *in group B* were varied as in group A.

1. A transvertebral paraffin injection at T10 was given in four dogs with the technique described previously. Laminectomy on T9 to T12 was performed 9 to 17 days later. The paraffin was not removed at laminectomy. The observation period was approximately 10 weeks.

2. Laminectomy on T9 to T12 was performed in four dogs, and before the surgical wound was closed, a transvertebral paraffin injection was given at T10. The period of observation lasted approximately 10 weeks.

3. In three dogs, subjected to laminectomy on T12 to L2, paraffin injection was given at the disk between T13 and L1 via the laminectomy opening. The observation period was four to five weeks.

RESULTS

A summary of the results is given table I.

Functional disturbances.—Of the four animals (group 1) that had received a paraffin injection 9 to 17 days prior to laminectomy, one had mild paresis (grade I) after injection, one moderate paresis (grade II), one subtotal paralysis (grade III) and the fourth animal had spastic paralysis (grade III). All these animals showed progressive improvement in the period between the paraffin injection and laminectomy. At the time of laminectomy one dog exhibited normal motor activity, two had moderate paresis (grade II), and the fourth had subtotal paralysis (grade III) with some persistent voluntary motor function. In two cases laminectomy on T9 to T12 caused a slight exacerbation of a few days' duration. Otherwise the dogs showed progressive improvement during the postoperative period. At the end of observation all the dogs were able to walk, although mild paresis (grade I) was present in three animals.

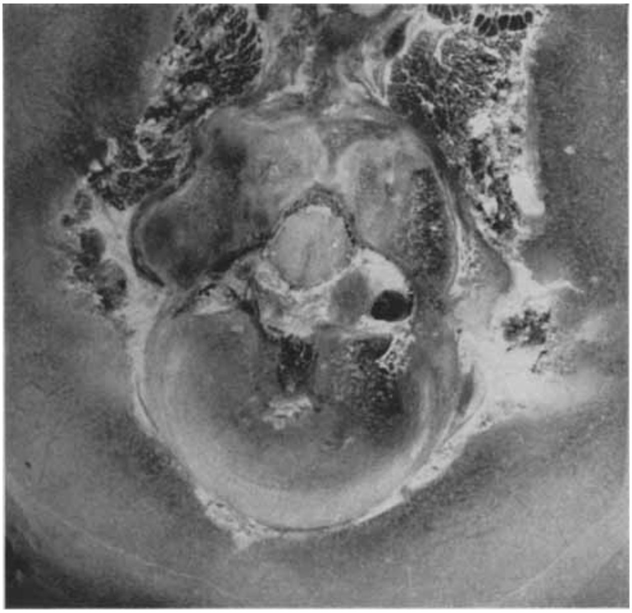

Fig. 8. Cross-section through the disk T10/T11. Laminectomy on T9-T12 according to technique B with simultaneous elevation of the cord by transvertebral injection of paraffin wax. The dog had, in general, a normal motor activity immediately after the recovery from anaesthesia and during the whole time of observation. The animal was destroyed about 10 weeks after the operation.
There is ample formation of bone and cartilage from the inside of the retained parts of the articular processes. The remaining narrow cleft in the roof of the spinal canal is bridged by fibrous connective tissue. A ventral paraffin mass elevates the cord and its meninges to such an extent that the distance between the ventral surface of the dura and the bottom of the canal approx. corresponds to $^1/_2$ a normal cord diameter. The cross-section of the cord has a normal shape.

Two of the four dogs (group 2) that had been given a transvertebral paraffin injection immediately after laminectomy of the abovementioned type on T9 to T12 displayed no functional disturbances postoperatively, whereas one animal had moderate paresis (grade II) and the other subtotal paralysis (grade III). The lastmentioned dog was unable to walk, although some voluntary motor function remained. Both of these latter animals showed progressive improvement. At the time of sacrifice three dogs exhibited normal motor activity, and the fourth, which initially had had subtotal paralysis, now presented mild paresis (grade I).

Of the three animals (group 3) that had received a paraffin injection via the laminectomy opening after laminectomy on T12 to L2, one exhibited normal motor activity postoperatively while the oher two had moderate paresis

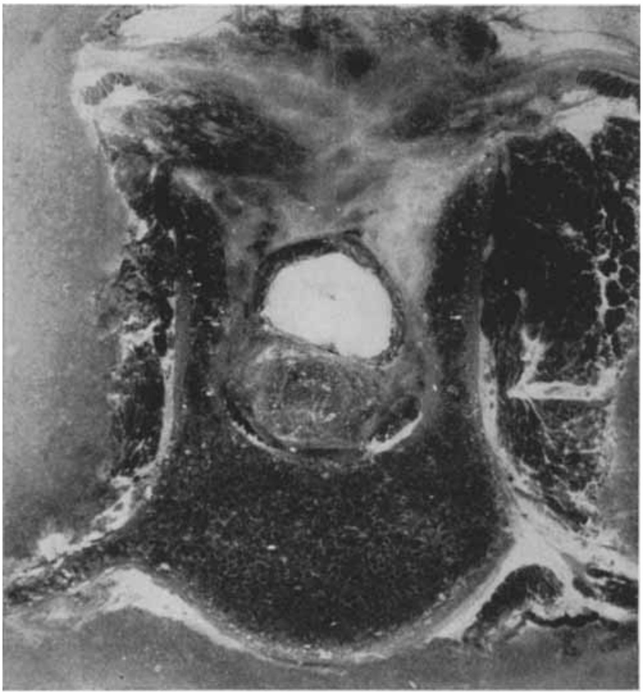

Fig. 9. Cross-section close to the disk L1/L2. Laminectomy according to technique B with simultaneous elevation of the cord as described under "7". After recovery from the anæsthesia the dog showed almost normal movements, which persisted to the end of the observation time. The animal was destroyed about 5 weeks after the operation.
The defect in the roof is bridged by fibrous connective tissue. Ventrally in the epidural space there is a paraffin mass that elevates the cord and its meninges to such an extent that the distance between the ventral surface of the dura and the bottom of the spinal canal corresponds to approx. 1 normal cord diameter. There are no signs of cord deformation caused by shrinkage or proliferation of tissue.

(grade II), but were able to walk. These two animals showed progressive improvement. At the end of the observation period two animals showed normal function, and signs of mild paresis were present in the third.

Patho-anatomic changes.—The reaction of the spinal column was largely identical with that described for the corresponding operations in Part I. In this series too, some animals showed considerable bone and cartilage production from the medial surface of the remaining parts of the articular processes.

Irrespective of the influence of paraffin injections, the effect of the operations on the cross-section of the spinal cord was also the same, in principle, as

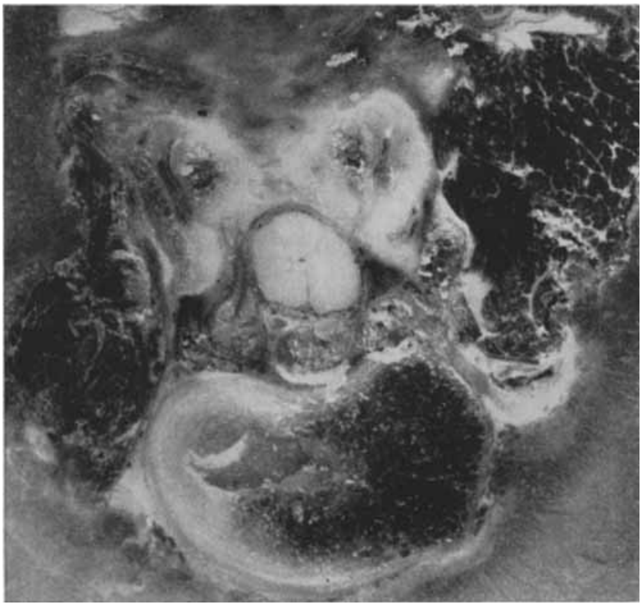

Fig. 10. Cross-section through the disk T13/L1 of the animal which has been described under fig. 9.
Ample formation of bone and cartilage on the inside of the remaining parts of the articular processes. The remainder of the defect is filled with fibrous tissue. The cord and its meninges are elevated to such an extent that the distance between the ventral surface of the dura and the bottom of the canal corresponds to approx. $^3/_4$ of a normal cord diameter. In the median plane and to the left, there is ample space vertically for the cord, but to the right there is a dorso-lateral flattening of the cord section corresponding to the above mentioned proliferation of bone and cartilage.

that reported in Part I under B;i.e., there was no considerable dorso-ventral compression of the cord but in some animals a tendency to lateral flattening. Those changes of the shape of the cord which are referable—directly or indirectly—to the injection of paraffin are described below.

In the majority of those animals (groups 1 and 2) that had received transvertebral paraffin injections the paraffin had passed to the side of the spinal cord and displaced it in the lateral direction, and, as a rule, caused an impression in the cord. Only in three of the animals that had been given transvertebral injections (all in group 2) had the bulk of the paraffin remained on the ventral aspect of the cord and thereby caused an elevation of the latter corresponding approximately to one-half to one normal spinal cord diameter. No dorso-ventral compression of the cord was demonstrable in these animals (fig. 8). In all three animals subjected to laminectomy at T12 and L2 and injected with

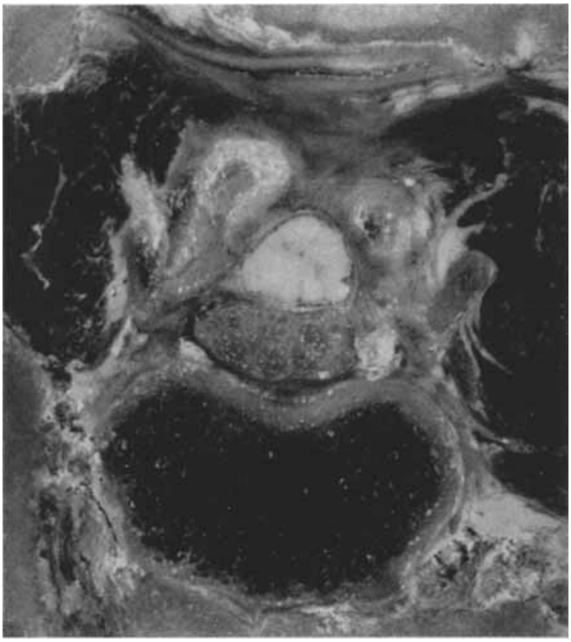

Fig. 11. Cross-section close to the disk T13/L1. The conditions of the experiment were identical to those that have been described under fig. 9. After the recovery from anaesthesia the animal had signs of a moderate paresis (grade II) of both hind legs. The condition has since gradually improved and at the end of the observation time there was only a slight paresis (grade I). The animal was destroyed 4 weeks after the operation.
Ample formation of bone and cartilage on the inside of the remaining parts of the articular processes (observe especially the left of the picture). The remaining defect in the roof is filled with fibrous connective tissue. The cord and its meninges are elevated by a ventral paraffin mass to such an extent that the distance between the ventral surface of the dura and the bottom of the canal corresponds to approx. $^3/_4$ of a normal cord diameter. In the vertical direction the space available for the cord is sufficient both in the median plane and to the right of it. To the left, there is a dorso-lateral flattening of the cord corresponding to the proliferation of bone and cartilage from the inside of the articular processes.

paraffin via the laminectomy opening, the paraffin mass lay ventral to the cord and elevated the latter approximately one-half to one normal cord diameter. Neither in this group was there any considerable dorso-ventral cord compression; the cross-section of the elevated part of the cord showed, however, dorsolateral flattening which was invariably most pronounced above the intervertebral disks. The shape of the cross-section of the cord was in good agreement with the borderlines of the newformed bone and cartilage on the inner surfaces of the remnants of the articular processes (figs. 9, 10 and 11).

DISCUSSION

The patho-anatomic findings are in good agreement with the assumption made in Part I that the dorso-ventral flattening of the cord observed after excision of the dorsal portion of the arch (including the articular processes) is caused by shrinkage of granulation tissue formed during healing of the post-laminectomy defect in the dorsal wall of the spinal canal. On scar contracture this tissue may form a membrane that is tightly stretched between its points of attachment to the cut surfaces of the arch, thus compressing the cord ventralward. The above assumption is supported–*inter alia*–by the observation reported above that (after laminectomy with the A technique) the tendency towards spinal cord compression was considerably less in the thoracic region than at the thoraco-lumbar junction, and that this difference seems to be related to the fact that after laminectomy in the former region the tissue bridging the surgical defect was attached largely to the transverse processes and to the ribs; i.e., to points situated at a high level in relation to the base of the spinal canal.

The main purpose of the current experiments was to elucidate the effect of healing on the spinal cord after extensive laminectomy with the two operative methods described in Part I, when the cord had been displaced dorsally at the beginning of the healing process, as it may be, for instance, by median herniation of a disk. In the first experimental series paraffin injections were given, for technical reasons, at the level of the disk between T10 and T11 instead of between T13 and L1. (The latter site of injection would have afforded a possibility of direct comparison with those experiments (Part I) in which laminectomy had been performed without paraffin injection). The thoracic laminectomy experiments were found to be unsuitable for elucidation of the above-mentioned problem, mainly for two reasons. On the one hand, the tendency towards post-laminectomy cord compression proved, on the whole, to be considerably less pronounced in this region than in the former operative region; on the other hand, at transvertebral injection the paraffin mass passed largely to the side of the median plane and thus did not bring about the desired elevation of the spinal cord. In cases where the cord actually was elevated, moderate dorso-ventral compression was demonstrable, at patho-anatomic examination, in those animals in which the dorsal and dorso-lateral parts of the arch had been completely excised with the A technique, but in those where the outer parts of the arch had been spared at laminectomy with the B technique, the cord deformation was limited to the aforementioned slight lateral or dorso-lateral flattening. The difference in the two operative methods with respect to the tendency towards compression *in this region* was not great enough to be reflected in a conspicuous difference in the functional behaviour of the spinal cord during healing. In the supplementary experimental series the operation was performed in the region of T12 to L2, whereby, for technical reasons, the paraffin was introduced instead via the laminectomy opening and caused a substantial elevation of the spinal cord in all animals. In those of the last-mentioned series of experiments which involved total excision of the dorsal and dorso-lateral portion of the arch, the animals initially showed progressive improvement of the motor loss symptoms, but after approximately two weeks signs of rapidly progressing damage to the spinal cord appeared, and, after a further two weeks, subtotal or total paralysis of the hind legs developed. Apart from symptoms of motor loss following upon the operation and progressively decreasing, corresponding animals subjected to laminectomy with *retention of the outer compact bone of the dorso-lateral part of the arch,* showed no neurological symptoms over a similar period. In dogs of the firstmentioned group the spinal cord was found, at patho-anatomic examination, to be compressed to a thin plate between the paraffin mass and the scar tissue, whereas the animals of the latter group showed no dorso-ventral flattening of the cord, even though the dorsal displacement was so great that the cord was situated largely in the excavated part of the arch. In these latter dogs moderate lateral or dorso-lateral flattening of the cord was demonstrable. The last-mentioned type of deformation seems to be caused for the main part by formation of bone and/or cartilage originating from the injured articular processes.

The results obtained seem to warrant the conclusion that the process of healing in dogs after extensive laminectomy with complete excision of the dorsal and dorso-lateral parts of the arches including the articular processes (technique A) may entail a risk of severe spinal cord compression, while this complication could be avoided when the dorsal portion of the arch including the articular processes had been spared at laminectomy (technique B). Whether it is possible with technique B to attain a *permanent* safeguard against secondary spinal cord compression—caused by scar shrinkage or proliferative processes—cannot be deduced from our results owing to the short observation times. Experiments with longer periods of observation in animals with spontaneous compression of the cord (herniated disks)—which experiments will be reported separately—suggest, however, that the risk of complications after type B laminectomy is inappreciable even in the long run. Should the abovementioned results be confirmed by further experiments with this operative method, it would thus be justifiable to restrict operations for median hernia to decompressive laminectomy and to retain the bulk of the prolapsed disks, provided the operative technique is such as to afford an adequate safeguard against secondary dorsal spinal cord compression.

It was found that the abovementioned experiments in which transvertebral injection of paraffin had been given in conjunction with thoracic laminectomy, did not permit comparison of the two surgical methods in respect to the risk of secondary compression of the spinal cord. They may, nevertheless, be of some surgical interest, for the following reason. Vaughan (1958) and Olsson (1960) hold the view that the surgical trauma at laminectomy performed on dogs when the spinal cord is already damaged, may involve a risk of transforming a reversible into an irreversible lesion of the cord. The abovementioned experiments in which laminectomy was performed at a second operation *after the paraffin injection* suggest that the surgical trauma associated with this technique does not have any significant deleterious effect on the cord. The operations in question either had no effect whatsoever on the neurological status or caused only a transient impairment of motor function. In this connection, however, it must be pointed out that the operations were performed a relatively long time (8 to 17 days) after the initial trauma; hence the experimental conditions were not altogether comparable to those obtaining in spontaneous spinal cord compression.

The experimental elevation of the cord by means of paraffin injection in the ventral epidural space *after opening the dorsal wall of the spinal canal at laminectomy,* may throw some light on the therapeutic significance of rhizotomy or division of the dentate ligaments in cases with corresponding degrees of spontaneous elevation of the cord by pathological processes. It has been considered that since the spinal nerve roots and the dentate ligaments fix, respectively, the dura to the base of the spinal canal and the spinal cord to the dura, they may contribute substantially to the occurrence of spinal cord lesions associated with ventral expansive processes (Kahn 1947, Logue 1952, and Tovi & Strang 1960, among others). The fact that the motor disturbances in the experiments reported in B 3, were relatively slight and progressively abated throughout the observation period, even though very pronounced elevation of the cord was present and no rhizotomy or division of dentate ligaments had been done, suggests that the ventral fixation of the cord by the nerve roots and the dentate ligaments is not, in dogs, of major causal significance in spinal cord lesions caused by ventral compression at the junction of the thoracic and lumbar regions.

SUMMARY

Laminectomy at the junction of the thoracic and lumbar regions (T12 to L2) was performed on dogs by a technique involving excision of the dorsal and dorso-lateral portions of the arch including the articular processes. In connection with laminectomy the spinal cord was elevated by means of an injection of paraffin wax into the ventral epidural space. During healing these animals

exhibited severe dorso-ventral compression of the spinal cord with total or subtotal paralysis of the hind legs. When the outer compact bone of the dorsolateral portion of the arch including the main part of the articular processes was spared at laminectomy—the other experimental conditions being unchanged – dorso-ventral cord compression was prevented. At corresponding operations in the thoracic region (T9 to T12) the tendency towards cord compression was conspicuously less even after laminectomy with the first-mentioned technique.

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