ANNALS OF SURGERY

VOL. 137 APRIL, 1953 No. 4

EXPERIMENTAL OBSERVATIONS OF CONCUSSION AND CONTUSION OF THE SPINAL CORD*

L. W. FREEMAN, M.D., PH. D., AND T. W. WRIGHT, M.D.

INDIANAPOLIS, INDIANA

FROM THE SURGICAL EXPERIMENTAL LABORATORIES, DEPARTMENT OF SURGERY, INDIANA UNIVERSITY SCHOOL OF MEDICINE

ONE OF THE MOST difficult and controversial problems which confronts neurosurgeons today is that of choosing the best treatment for patients suffering from injuries of the spine with concomitant injury to the spinal cord. Traumatic injury to the spinal cord usually results in paraplegia. Whether this paraplegia is complete or incomplete is dependent, in part, upon the severity of the injury imposed upon the neural tissue. Whether any degree of functional recovery will ensue is dependent upon factors largely unknown. It is well known that the spinal cord is a delicate structure, and following injury, conductive function is inhibited. When this inhibition of conductive function is temporary, the paraplegia is spoken of as "physiological." Conversely, when it is permanent, the syndrome is spoken of as an "anatomic" interruption.

HISTORICAL REVIEW

There is ample historical background[28] for the confusion that exists today. The early Egyptians recognized the syndrome of paraplegia following spinal cord injury, and Celsus[8] remarked upon the hopeless prognosis for such patients. The surgeon's fear of incising the dura mater was founded in the early centuries, was fostered in the eighteenth century by such great clinicians as Berengarius,[4] and was projected into the twentieth century in the era preceding antisepsis. On the other hand, Paul of Aegina[1] advised the removal of fractured laminae, and Ambrose Paré[22] operated for depressed splinters of bone or fragments impinging upon the cord and nerve roots as early as 1549. It is small wonder that bold surgery of this type did not receive popular support, for anesthesia and antisepsis were yet to come. Sporadic support for surgical intervention was noted, but a single case treated by Cline[9] was frequently cited as an indication for non-surgical therapy. Following this case report, the expressed opinion was rather uniformly against operative intervention.

Pressure for reduction of dislocations of the spine was used in the time of Hippocrates.[15] Paré[22] used traction for reduction, and Mathijsen[20] introduced fixation by plaster of Paris. Burrell[7] added the mechanical rectification of the deformity before application of the cast. For cervical spinal dislocations, Taylor[27] introduced halter traction, and Crutchfield,[11] at Coleman's suggestion, applied skeletal traction.

Cushing[12] in 1905 incised the pia mater over the posterior columns in a case of

* This work was aided in part by a grant from the Veterans Administration and is published with the permission of the Chief Medical Director, Department of Medicine and Surgery, Veterans Administration, who assumes no responsibility for the opinions expressed or conclusions drawn by the author. Presented at the April 12, 1952, meeting of the Southern Neurosurgical Society, Durham, North Carolina. Submitted for publication October, 1952.

intramedullary growth with paraplegia and was surprised by the degree of improvement following this simple procedure. This principal was applied by Elsberg[13] and amplified into the two stage extrusion technic for such tumors. A number of surgeons incised the pia mater for the purpose of drainage of syringomyelia, the most recent approach being that of the permanent drain of Kirgis and Echols.[19]

Many eminent clinicians expressed opinions upon the vexing problem of spinal cord injury, but it was not until Bastian[3] and Bruns[6] formulated the working hypothesis that all reflex activity was lost permanently when the spinal cord was severed that a majority expression was gained. This concept was in sharp contrast to that presented by Schiefferdecker,[25] which was reestablished many years later by the brilliant observations of Head[14] and his co-workers at the Spinal Center during and shortly after the first World War. Indeed, Sherrington[26] supported the concept of isolation dystrophy (and thus permanent loss of all reflex activities). Subsequently, he altered this position, pointing out that he had used the sciatic nerve, severed by cage sores in his primates, as a representation of the status of the distal stump of the divided spinal cord.[10] In the early twentieth century, Ramon y Cajal[24] was presenting his findings on neural regeneration. His staining technics were hailed widely but, perhaps due to an inability to translate properly the writings, American writers indicated that Cajal felt that regenerative phenomena in the spinal cord were either absent or were so abortive as to be of no consequence. As a matter of fact, Cajal was very careful to detail many conditions which would prevent regeneration, conditions which were duplicated by almost every human patient being treated.

Leaving aside the controversial question of central nervous system regeneration and dealing only with the problem of preservation of intact neural structures, A. R. Allen[2] reported in 1911, on experimental lesions of the spinal cord. He demonstrated that an otherwise "fatal" injury directed to the spinal cord could be reversed by surgical attack. This feeling was projected into the clinical thinking of a very few, and through neglect, died of an unnatural death.

Late in the last world conflict many of the newer generation of neurological surgeons began to have reason to question the dictates of their predecessors. It became clear to them that it was not possible to distinguish between anatomic and physiologic division of the spinal cord. It was the feeling of some that the spinal cord lesion had ceased to be a neurologic curiosity and had returned to the realm of the surgeon. In the war years, it became necessary for the directive personnel of the Army Medical Establishment to issue orders preventing the overly enthusiastic field surgeons from entering the spinal canal. However, those surgeons encountering patients with spinal cord injuries in sufficient numbers soon were impressed by the relatively large numbers of patients with apparently transected cords who walked again—usually in spite of treatment.

One can turn to data such as those presented by Kimbrough[18] on suprapubic cystotomy for paraplegia from the European invasion to see that not infrequently someone along the line had condemned a patient to spastic paraplegia only to have that patient regain full function. Indeed, the presentation of McCravey[21] indicated that definite aid could be afforded to patients with spinal cord injury by surgical intervention.

Rehabilitation of paraplegic patients reached a fair degree of perfection during and shortly after the last World War. Yet this has always been a poor substitute for return of function. Since preservation or return of function is the preferable goal, our interests have been leveled, for the past seven years, at the questions centering around this possibility. It is the purpose of this communication to present experimental data compiled in a test of the hypothesis that trauma to the spinal cord lies within the realm of surgically amenable disorders. Specifically, it is hypothecated that indirect trauma rarely induces anatomic disruption of major pathways in the spinal cord and that the ultimate effects represent a physiopathologic response which may be reversed.

METHODS

A wide variety of traumata were attempted in an effort to produce a standard type of injury. Almost all of the methods suffered from a common criticism, that of irreproducibility. It became obvious that indirect trauma could not be applied to the average laboratory experimental animal. Consequently a method was devised patterned after that of Allen,[2] in which a given weight was dropped a known distance upon the exposed spinal cord and investing membranes with the impact being calculated in gram-centimeters of force.

In practice, a lucite rod, concave at one end, was placed vertically upon the spinal cord and its investing membranes exposed in the mid-dorsal region. A glass tube was then placed over this lucite "impounder," and a weight, a mercury filled glass rod, was dropped through the glass tube upon the cord "impounder." In the preliminary survey, 78 rats of the Wistar-Harlan strain under intraperitoneal pentobarbital sodium anesthesia were subjected to cord traumas varying from 5 to 50 gram centimeters. These animals were evaluated as to the degree of motor impairment on the day following surgery. Other experiences with permanently paraplegic animals indicated that the most favorable animal would be one which was not rendered permanently paraplegic, because of the low rate of survival of such animals. When a value of force was established which would usually result in paraplegia, 81 animals were studied in the following way. Seventeen were subjected only to laminectomy as a control upon the operative procedure, 28 were subjected to laminectomy plus trauma to the cord, and 36 were subjected to a laminectomy plus trauma plus an immediate incision of the pia mater, followed by a blunt myelotomy. This incision was made longitudinally into the mid-dorsal region of the spinal cord and extended for the entire length of the laminectomy, through approximately one-half of the thickness of the spinal cord. Postoperatively, general maintenance was established, and routine manual expression of the bladder was done four times daily until the bladder became automatic.

Small, healthy adult female mongrel dogs were dewormed, mange-dipped, and

TABLE I.—*Effect of Trauma Upon the Exposed Spinal Cord of Rats.*

Force of Trauma in Gram-centimeters	Number of Animals	Motor Function 24 Hours After Trauma: Essentially Normal	Moderate Impairment	Marked Impairment	Paraplegia
5	2	2			
10	2	1		1	
15	10	3	2	1	4
20	7	2	1	1	3
25	18			2	16
30	9				9
35	9				9
40	8			1	7
45	8				8
50	5				5

TABLE II.—*Comparison in Rats of Results Following Laminectomy Alone, Laminectomy Plus 25 Gram-Centimeter Trauma, and Laminectomy Plus 25 Gram-Centimeter Trauma and Cord Incision.*

Procedure	Per Cent With Good Walking Function: 7th Day	14th Day	21st Day	Mortality
Laminectomy Alone (17 rats)	94.1	94.1	94.1	5.9
Laminectomy Plus Trauma (28 rats)	3.6	25.0	42.8	50.0
Laminectomy Plus Trauma And Cord Incision (36 rats)	11.1	36.1	55.5	38.8

brought into positive nutritional balance. Using aseptic technics, a mid-dorsal laminectomy was performed under intraperitoneal pentobarbital sodium anesthesia. The epidural tissue was removed, and a larger model of the trauma producing apparatus was used. Forces ranging from 340 to 500 gram-centimeters were used. When levels of trauma had been established, animals

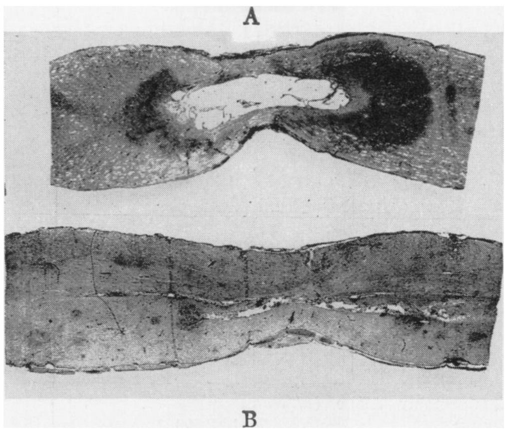

FIG. 1.—Comparison between longitudinal sections of the spinal cords of an untreated dog A (1–437) and a treated dog B (13–475), both of which were subjected to 360 gram-centimeters of trauma. Note the large cavity in A with the multiple smaller ones throughout the section. Note also the large amount of surviving white matter in B.

were paired as closely as possible as to size and general appearance. Each of such pairs was subjected to laminectomy and trauma. The wound of one was then closed in layers. In the other animal of the pair, the dura mater was opened for the full length of the laminectomy and the edges were held by traction sutures. The pia mater was then incised sharply with a cataract knife, avoiding whenever possible, any major surface vessels. A blunt probe was then passed approximately half way into the cord between the dorsal columns and was drawn longitudinally for a distance of 15 mm. Warm saline was then directed in a gentle stream into this incision. Usually, necrotic cord and dark bloody material were washed out. Hemostasis was established with gelfoam. A piece of gelfoam was placed over the area. Wounds in all animals were closed in layers with interrupted black silk sutures.

In another series of dogs, paired animals were studied in the following fashion: After exposure of the laminar arches in the mid-dorsal region, a single laminar arch was fractured bilaterally with an osteotome and a hammer. This arch was then swung to one side and the impounder was set in place. Occasionally, the defect had to be enlarged with a rongeur. The blow was delivered. In the control animals, the lamina was refitted and sutured in place, and the wound was closed in layers. In the experimental animals, formal laminectomy of the involved and adjacent vertebrae was carried out. The dura mater was opened and held by traction sutures. The pia mater was incised sharply in the mid-line over the entire laminectomy and the dorsal columns were entered with a blunt probe as previously described, except that the incision was much longer. Irrigation was also carried out. In most of the animals, the dura mater was left open, but in some, it was closed tightly. The wounds were closed in layers with interrupted black silk sutures. A few animals were subjected to osteoplastic laminotomy alone.

Postoperatively, all dogs were enclosed in a plaster jacket which held a wire loop. A Kirschner wire was passed through a tail vertebra. The animals were then suspended in a stock. Bladders were expressed two times daily in early animals and three times daily in all later ones. Careful watch was kept on fluid and food intake. Neurological examinations were conducted at frequent intervals, and when function seemed to be returning, the suspending apparatus was removed. Antibiotic therapy was used whenever indicated. Casts and wires were replaced when necessary.

Except in unusual circumstances, all cords of rats were preserved by removing the vertebral columns and placing them in 10 per cent formalin solution. Serial sections were made, using a modification of the Bodian on-slide silver technic for most slides.[5] In dogs, dial with urethane anesthesia* was given, the spinal cord was stimulated above and below the level of trauma with varying parameters, effects of stimulation were noted, and the cord was removed and placed in formalin solution. These cords were prepared for longitudinal serial sections in the area of trauma and cross sectional slices of the proximal and distal stumps. Conventionally, the same silver technic was used, with special stains being prepared in selected specimens.

RESULTS

The graded force applied to the exposed thoracic spinal cords of rats showed that 24 hours after administration of the trauma, all animals subjected to 25 gram-centimeters or more were either paraplegic or severely impaired (see Table I). When laminectomy plus cord trauma and laminectomy plus cord trauma plus cord incision were compared, good walking function was noted more regularly in the latter group (see Table II). Early mortality was about the same, but the animals with laminectomy alone, having survived anesthesia and operation, all lived without impaired function. The control group (sic) had greater mortality (50 per cent) and fewer animals which recovered good walking function than the experimental group.

In the survey of force required to produce lasting paraplegia in dogs, Allen's data were considered as a basis for the range of trauma. The data for this study are contained in Table III. Dogs subjected to laminectomy alone suffered no impairment of function. Since short range observation was used in this phase, it was concluded that 350 to 375 gram-centimeters was sufficient to produce lasting paraplegia in most instances. When animals were paired, with one receiving median longitudinal incision, after 360 gram-centimeters or more of trauma, it was apparent that a significant number were benefited by this procedure (compare Tables III and IV). For example, no animal out of six subjected to laminectomy and 400 gram-centimeters of trauma alone regained any function during the time that they were observed, whereas three of nine with the same amount of trauma and median longitudinal incision

TABLE III.—*Results Following Laminectomy and Cord Trauma in Dogs.*

No.	Force in Gram-centimeters	Walking		Day of Death or Sacrifice		Response to Stimulation of Cord	Remarks
		Day Began	Function Attained	Death	Sacrifice		
298	340	3	Fair	..	3	..	None.
301	350	..	..	..	5	None	Reflex standing only.
305	350	..	..	..	9	None	Wound infection.
302	360	..	..	..	11	..	Always flaccid.
311	360	6	Normal	..	103	..	None.
299	375	..	..	..	13	..	Continued spastic.
314	375	25	Poor	..	38	None	Progressive downhill course.
318	375	..	..	..	21	None	Spastic reflex activity.
319	400	..	..	12	..	..	Spastic reflex activity.
337	400	..	..	37	..	..	Reflex standing on 28th day.
340	400	..	..	21	..	..	Continued spastic.
348	400	..	..	24	..	..	Spastic reflex activity only.
351	400	..	..	27	..	..	Spastic reflex activity.
355	400	..	..	9	..	..	Spastic extension.
300	425	..	..	..	15	None	Continued spastic.
297	462	..	..	..	8	..	Continued spastic.
327	500	..	..	..	14	..	Continued spastic.

* The dial used in these experiments was supplied by Dr. Jock L. Graeme of Ciba Pharmaceutical Products, Inc., Summit, New Jersey.

walked quite well, and another later gained some walking ability. Even at the severest trauma used (500 gram-centimeters), the treated animal walked, albeit poorly.

In the series of dogs in which the spinal cords of controls were exposed by laminotomy and the laminar arches were replaced following administration of the trauma, only four of 12 animals regained any degree of function. Of these four dogs, two were severely incapacitated (see Table V). In contrast, those animals which had a laminectomy and debridement of the spinal cord, eight of ten showed some degree of functional recovery (see Table VI). Of the control dogs, one walked almost normally, one had a weak right leg, and the other two had difficulty in gaining and maintaining quadriped support and locomotion. In the experimental animals, two were considered to be normal, one walked with only traces of disability, four walked with minor disabilities, and one could walk only short distances.

Stimulation studies correlated extremely well with functional observations. On the other hand, microscopic examinations were more difficult to tabulate. In Figure 1 is shown a comparison between dog 1--437 (Table V) and dog 13-475 (Table VI). It was not an invariable finding, but the degree of cystic cavitation related well to the final functional result. Where the cystic cavities were observed to be closed, function was not present or, if it was, it was not as good as in a paired animal without the cavity. In animals which showed no functional return, no intact neural tissue could be identified. In those animals with functional activity, intact neural tissue was present. On the average, it appeared that less than 70 per cent of the cross-sectional area survived more than 360 gram-centimeters of trauma, but this amount of tissue could support walking indistinguishable from normal. Areas of intact tissue were usually situated peripherally. Grey matter rarely survived. Next in order, the dorsal columns failed to survive, especially in the juxtagriseal areas. Gross inspection gave the impression that unincised cords generally had cysts which bulged, but when the cords were removed, they collapsed. In contrast, incised cords often had no cyst and showed only a local constriction. Degeneration and regeneration studies have not been completed as yet.

TABLE IV.—*Results Following Laminectomy, Cord Trauma, and Median Longitudinal Incision in Dogs.*

No.	Force in Gram-centimeters	Walking: Day Began	Walking: Function Attained	Day of Death or Sacrifice: Death	Day of Death or Sacrifice: Sacrifice	Response to Stimulation of Cord	Remarks
306	360	14	Normal	..	93	..	......
317	375	..	..	..	36	Good	Developed active motion.
325	400	8	Normal	..	76	..	......
332	400	9	Normal	19	..	..	Died of dystemper.
333	400	..	..	13	..	..	Reflex movement only.
336	400	..	..	12	..	..	Reflex movement only.
344	400	..	..	..	57	..	Able to stand (not reflexly).
346	400	13	Poor	15	..	..	Died of unknown cause.
349	400	..	..	..	8	..	Inability to maintain care.
350	400	..	..	..	53	..	Minimal reflex activity.
354	400	144	Fair	..	404	Good	......
329	500	43	Poor	..	75	..	Walking improved then regressed.

DISCUSSION

A review of the literature or a survey of current opinion on the question of spinal cord concussion and contusion would reveal as large an element of confusion as that existing in reference to cerebral injuries. Perhaps the foremost reason for this confusion rests upon the basis that an adequate measure of trauma is not possible. When one considers the vast variety of traumata to which the spinal cord is exposed and compares this with the same possible range of variation in response, one realizes that there are other factors than biologic variability. In other words, there are presently no adequate means of precise determination of the force of trauma in a given animal.

Conventionally, an effort has been made to distinguish between "anatomic" and "physiologic" interruption of function of the spinal cord. In this approach, final functional status is used as the index, for if return is observed, only "physiologic" disruption has occurred. Except for unusual circumstances, it has not been possible to relate the type and severity of trauma to the final functional outcome. Because of the multiplicity of disabilities which follow spinal cord injury, it has not been possible, until recent times, to maintain life in spinal cord injured patients for long periods of time. Thus, there has been a practice that prognostication is based upon functional development, and even upon level of lesion. It is not difficult to gain approval of the opinion that roentgen examination does not give a true index of the maximal insult to the spinal cord. But the past world conflict found too many people confused about the differentiation between anatomic and physiologic disruptions of spinal cord function to find reasonable areas of agreement.

Under ordinary circumstances, it appeared that trauma other than high velocity missiles could be divided into categories of those which severed the anterior longitudinal ligament and those which did not. One could presume that an injury sufficient to rupture this powerful ligament would find little difficulty in performing an anatomical severance of the cord. Yet, if this force (the power of the anterior longitudinal ligament) were not overcome, how could one grade the injury? It is obvious that between the vertebral injury with no spinal cord involvement and the vertebral injury with complete cord involvement, there must lie a variable zone of reaction.

It was one of the purposes of this experimentation to attempt a definition of irreversible spinal cord trauma. The data accumulated to date indicate that many factors must be considered. Among these are force, time, nutrition, hydration, probably age, possibly emotional factors, and others. Efforts were made to control all of these variables by proper matching of paired animals. The experimental situation has been artificial, and yet it has served to elucidate fundamental considerations. It is apparent from the data that, all factors considered, presumably irreversible lesions can be reversed.

TABLE V.—*Results Following Osteoplastic Laminotomy and Cord Trauma in Dogs.*

No.	Force in Gram-centimeters	Walking: Day Began	Walking: Function Attained	Day of Death or Sacrifice: Death	Day of Death or Sacrifice: Sacrifice	Response to Stimulation of Cord	Remarks
364	350	..	..	2	..	..	Perforated chest.
367	350	..	..	2	..	..	Death from unknown cause.
366	350	..	..	9	..	..	Infected operative site.
1-437	360	23	Poor	..	72	Poor	Stimulation response on right only.
3-439	360	21	Good	..	105	Good	Walking almost normal.
6-445	360	135	Poor	..	191	Poor	Never had quadriped support.
11-473	360	23	Good	..	138	Good	Right leg weak.
14-485	360	..	..	..	139	None	Could not stand.
15-487	375	..	..	..	141	None	Could not stand.
16-6	360	..	..	..	73	..	Could not stand.
18-32	375	..	..	59	..	..	Could not stand.
20-56	375	..	..	5	..	..	Death from unknown cause.

In the screening experiments on rats, reading was done at 24 hours in order that the appraisal would be similar to that in the usual clinical situation and to allow for complete recovery from anesthetic effects. By and large, 25 gram-centimeters of force gave a complete paraplegia which persisted longer than 24 hours, as did greater forces. When animals with 25 gram-centimeter traumata were observed for extended periods, some showed recovery (Table II). The presence of movement in one rat with 40 gram-centimeters of trauma probably represents an error in technic. On the whole, the data provided a good dividing line for testing the hypothesis that the pia mater served as the limiting membrane for reversible lesions.

In patients, herniation of cord material through small pial tears probably is quite disastrous. Yet, one is impressed by the large number of operative reports which indicate that it was the surgeon's considered opinion that the spinal cord was normal in appearance, only to have the same cord present itself at a secondary laminectomy as a hard band, nicely surrounded by intact pia. It was felt that the situation of spinal cord herniation was probably comparable to that of muscle herniation, wherein small fascial tears could lead to necrosis of extruded muscle while wide tears were not productive of this situation. Indeed, surgical therapy for such fascial tears often consists of widening of the tear. As edema superimposes itself upon hemorrhage and inflammatory reactions within the cord, the pressure effects would be taken up by superior and inferior transmission of these changes whenever the pia mater was intact, or whenever any pial openings became plugged by tissue. As this pressure increased, capillary circulation would cease, or would not be re-established after the initial insult, and anoxia would ensue. Thus, permanent damage could result from the sequelae of injury rather than from the direct effects of injury itself.

TABLE VI.—*Results Following Osteoplastic Laminotomy, Cord Trauma, Laminectomy, and Median Longitudinal Incision in Dogs.*

No.	Force in Gram-centimeters	Walking: Day Began	Walking: Function Attained	Day of Death or Sacrifice: Death	Day of Death or Sacrifice: Sacrifice	Response to Stimulation of Cord	Remarks
2–438	360	..	..	5	..	..	Gangrene both legs.
4–440	360	..	..	..	7	..	Gangrene right thigh; responds to painful stimulation.
5–442	360	18	Normal	..	105	Good	None.
7–447	360	16	Normal	..	106	Good	None.
8–452	360	64	Fair	..	186	Poor	After walking, gradually deteriorated. Very old dog with calcified heart vessels.
12–474	360	24	Fair	..	143	Good	Occasional right foot drop.
13–475	360	7	Good	12	..	..	Died of dystemper.
19–33	375	24	Fair	35	..	..	Died of dystemper.
21–57	375	53	Fair	..	..	..	Alive at 226 days.
23–60	375	159	Poor	..	212	Fair	Delivered litter of 4 on 57th day; became too heavy to suspend at 30 days.

Because most investigations of the central nervous system have dealt with the contents of the cranial vault, there has been a tendency to transfer the concepts garnered down the spinal axis. Yet there is every indication that such transposition is not warranted. Where extradural, subdural and subarachnoid bleeding are common complications of cranio-cerebral traumata, they are unusual in the spinal canal. The spinal cord has more protective structures and circumstances than the brain, but when these devices are overcome, there exists probably a lesser degree of resistance to injury. The vascular supply is probably not as fully protected by anastomotic channels as that of the brain. Indeed, it would appear, from unpublished data gathered in this laboratory, that spinal cord vascular supply is largely segmental. In any event, the resistance offered by the pia mater to expansion need be no greater than capillary arterial pressure, which it must have, since otherwise pial rupture would occur with each strain at stool or cough. Bilateral tractotomies are traditionally performed at different levels to avoid the symptoms of transverse myelitis, probably resulting from occlusion of the "pial escape mechanism" for the lateral relief of edema.

Hematomyelia probably enters the syndrome of spinal cord trauma more extensively than is suspected. Extravasated blood exerts its acute effects by pressure, and its chronic effects in scarring. Like any collection of blood in a vital area, it must find channels of drainage or it will produce damage. Such collections of blood have been implicated in the delayed effects of trauma in such disorders as multiple sclerosis and syringomyelia. The pressure required to disrupt neurological conduction is small, certainly less than that which will cause rupture of the pia mater. This is well exemplified in the observation previously cited of Cushing[12] on the intrinsic cord tumor which responded so well to "internal decompression," leading to Elberg's[13] two-stage extrusion method for removal of these tumors. Certainly, there must be a compensatory factor to slowly developing pressure, one of these being expansion of the pia. But in rapidly developing pressure, these mechanisms do not participate.

The screening experiments seemed to verify this hypothesis, and the next group of rats was set up to provide a test. The test was not as conclusive as one would ask of experimental material, but it gave room for question. Certainly, the data indicate that pial incision and median myelotomy did not harm the animals. In humans, the median myelotomy of Putnam[23] has been shown to cause no severe damage. Moreover, more animals did well with pial incision than without it. These observations led to the use of an animal with a larger spinal cord, for it was felt that the surgery was probably too crude for these small cords.

The average adult paraplegic dog which is cared for in a conventional manner shows a gradual decline in health which advances rapidly to death from intercurrent infection once cage sores develop. Kellogg[17] presented a method of care for chronic spinal dogs, which Shumacker had independently suggested. With the suspension device, animals can be well cared for in good health for long periods of time. It is important to emphasize the health of the animals, for negative nitrogen balance is the rule after severe injury and this situation would not be conducive to retention or recovery of function. Poor care and crude operative technic have probably been the principal difficulties in this type of experimentation. The same could be said for human patients, for the comparison is good.

As has been indicated in previous publications, adult animals are maintained in good nutrition with great difficulty. Also, uncasted spinal canals show a uniform progression to further damage by virtue of the undue strain placed upon the horizontally aligned spine. A case in point is the so-called "crazy-legs disease" of horses, a well known entity to the veterinarian. It is suggested that the primary consideration in this type of experimentation is postoperative care of superlative quality. Indeed, Cajal[24] gave up the use of completely paraplegic animals because of inability to maintain them in good health. The procedure of laminectomy can be very traumatic to spinal cord unless meticulous operating is done.[16]

In the screening experiments in dogs, a significant number of animals benefited from the cord incision and debridement

(Tables III and IV), being very obvious in the paired animals subjected to 400 gram-centimeters of trauma. When consideration is given to the fact that these control animals were already afforded treatment (since they had decompressive laminectomies), the improvement becomes more significant. When the next series was set up, it was felt that the controls should at least retain the original bony confines. Even in such circumstances, duplication of the average human injury with fracture-dislocation was somewhat remote.

In the human, there is most frequently an actual diminution in the confines of the bony and ligamentous casing of the spinal canal. Again, the marked differences between the treated animals and the controls is striking (Tables V and VI). These tables include animals in which the period of observation was too short. If these are excluded from consideration, the control group shows only two of eight with good function, and two others with relatively non-useful motion. With the same criteria being used for the experimental group, all regained some measure of function. Indeed, all but one had ambulating function. The contrast certainly is worthy of remark.

The material covered by these investigations demonstrates only that rapid debridement offers the best possibility for preservation of function. There remains the question of how long after injury this beneficial result can still be obtained. This factor is now under investigation.

The data clearly indicate that wide pial incision after trauma to the spinal cord is not harmful. Further, the data show quite clearly that better functional results can be expected when primary debridement of necrotic cord tissue and blood is conducted. The procedure probably provides drainage for the serpentine hematomyelic tracts which originate, in large part, at the site of trauma.

SUMMARY AND CONCLUSIONS

1. Data are presented on rats and dogs which were subjected to measured direct trauma to the exposed spinal cord. These data are compared with those obtained from paired animals subjected to primary debridement of the traumatized cord.

2. In rats, the operative procedure has been shown to be without harm, and if anything, beneficial. In dogs, this beneficial effect is exaggerated and definite.

3. It is suggested that human patients with trauma to the spinal cord should be afforded the possible benefit of this procedure rather than the simpler operations now used.

Acknowledgments. The critical appraisal and suggestions of Dr. Henry Schwartz and the helpful advice of Dr. Harris B. Shumacker, Jr., are gratefully acknowledged. Without the devoted assistance of technicians Catharine Walton and Van Riesberg, these experiments could not have been conducted.

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