Original article

Early neurosurgical intervention of spinal cord contusion: an analysis of 30 cases

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Keywords: *spinal cord; contusion; neurosurgery; rehabilitation*

Background The incidence of spinal injury with spinal cord contusion is high in developed countries and is now growing in China. Furthermore, spinal cord injury happens mostly in young people who have a long life expectance. A large number of patients thus are wheelchair bound for the rest of their lives. Therefore, spinal cord injury has aroused great concern worldwide. Despite great efforts, recovery from spinal cord injury remains unsatisfactory. Based on the pathology of spinal cord contusion, an idea of early neurosurgical intervention has been formulated in this study.

Methods A total of 30 patients with “complete” spinal cord injury or classified as American Spinal Injury Association (ASIA)-A were studied. Orthopedic treatment of the injured vertebra(e), internal fixation of the vertebral column, and bilateral laminectomy for epidural decompression were followed directly by neurosurgical management, including separation of the arachnoid adhesion to restore cerebrospinal fluid flow and debridement of the spinal cord necrotic tissue with concomitant intramedullary decompression. Rehabilitation started 17 days after the operation. The final outcome was evaluated after 3 months of rehabilitation. Pearson chi-square analysis was used for statistical analysis.

Results All the patients recovered some ability to walk. The least recovered patients were able to walk with a wheeled weight support and help in stabilizing the weight bearing knee joint (12 cases, 40%). Thirteen patients (43%) were able to walk with a pair of crutches, a stick or without any support. The timing of the operation after injury was important. An optimal operation time window was identified at 4–14 days after injury.

Conclusions Early neurosurgical intervention of spinal cord contusion followed by rehabilitation can significantly improve the locomotion of the patients. It is a new idea of a therapeutic approach for spinal cord contusion and has been proven to be very successful.

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Spine injury with spinal cord compression is usually handled orthopedically. After stabilizing the spine by internal fixation, the patients are kept in bed for a period followed by rehabilitation. Despite all efforts, neurological recovery remains very limited for patients admitted with “complete” spinal cord injury or classified as American Spinal Injury Association (ASIA)-A. After spinal cord injury, a cascade of events leads to a secondary injury of the spinal cord. The injury site is filled with necrotic debris, which causes expansion of tissue damage. Eventually, the secondary injury may reach a size extending well beyond the zone of the primary injury.[1-4] Based on the pathology of spinal cord injury, we formulated a new approach to early neurosurgical treatment of acute spinal cord injury. In theory, early debridement of necrotic tissues should cut short the process of secondary injury. It also serves as intramedullary decompression and reduces pressure on spared spinal axons still crossing the injury site. To test this treatment approach, we conducted the following study. The surgery involved a joint effort of orthopedists and neurosurgeons. Orthopedists first took care of the spine followed by neurosurgical treatments. The surgery was followed by a program of rehabilitation. Even in completely paralyzed ASIA-A patients, our results suggest that this treatment approach can yield dramatic functional recovery. Of the 30 cases treated in this study, all recovered some ability to walk at the end of three and a half months. Many recovered the ability to walk.

METHODS

Patients

MRIs were obtained on admission to locate and confirm the presence of a spinal cord injury. All subjects were

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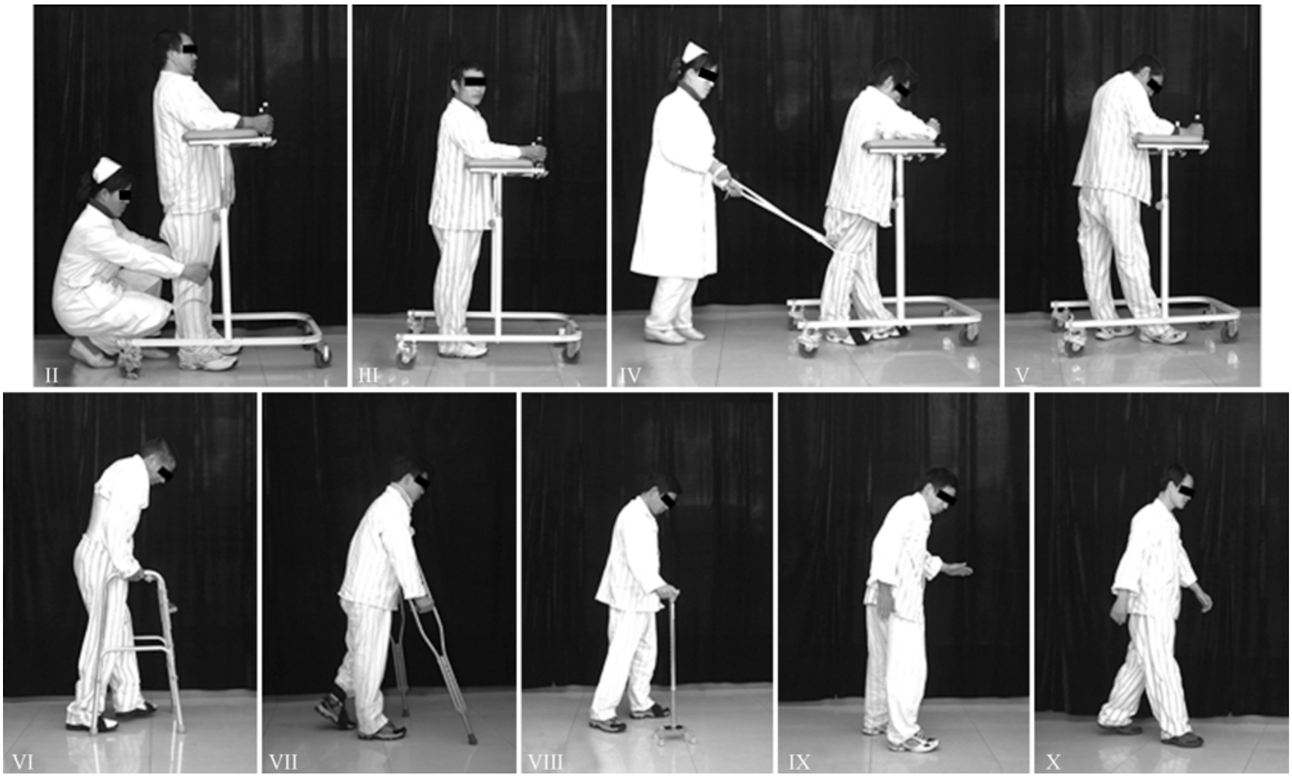

Figure 1. The 10-grade locomotion scoring system. Grade I is for patients who can not stand and is thus omitted from this figure.

initially evaluated to ensure that the subjects were ASIA-A, i.e. had no perianal sensation to touch or pinprick or voluntary contraction of the anal sphincter. None of the subjects were able to stand or walk before the surgery. All ASIA-A patients under the age of 50 who had been injured for no longer than two and a half months were non-selectively included in the study, except for the following. The exclusion criteria were: 1. the continuity of the cord had been completely destroyed. This was determined by observation during operation. Following debridement in lacerated severe contusion cases, the ventral spinal meninges could be clearly seen and the connection between the upper and lower spinal segments could be identified. Cases with any remaining connection were considered incomplete destruction of continuity. 2. Penetrating injury, the mechanism and course of recovery of which may be very different from that of contusion. 3. Patients with brain injuries or other neurological diseases. 4. Others: pregnancy, significant medical disease or infection and significant psychiatric conditions. Thirty cases were finally included in this analysis.

Treatments

Orthopedic surgeons surgically exposed the injured vertebra (e), internally stabilized the vertebral column and performed bilateral laminectomy for epidural decompression. The operation was then handed over to the neurosurgical team headed by one of the authors of this paper (Liu YS). The neurosurgery started with a dura incision and evaluation of cerebrospinal fluid (CSF) flow and surface appearance of the spinal cord. Every subject had complete blockade of the CSF flow and loss of rhythmic pulsations of the spinal cord associated with respiration. Because CSF flow is important for maintaining normal spinal cord metabolism, resumption of CSF flow was achieved by removing arachnoid adhesions. The spinal cord was then inspected. The injured site usually appeared rather pale. Gentler probing of the spinal cord was used to identify the injured part of the spinal cord. If a softened necrotic region was identified right beneath the pale surface, we categorized this type of injury as “severe contusion” (SC). In such cases, a 2–3 mm shallow longitudinal myelotomy would be carried out to allow necrotic tissue to gush out. We collected samples of the debris for pathological examination and washed out the remaining necrotic tissue in the cavity with a gentle stream of normal saline. If the spinal cord surface was disrupted, we categorized the injury as “lacerated contusion” (LC). If the location of the necrotic tissue could not be clearly identified, we categorized the injury as “mild contusion” (MC). To avoid possible additional injury of the spinal cord, myelotomy was not carried out in these cases. After surgery, the subjects were kept in the intensive care unit until they were medically stable. Thereafter, we avoided any experimental medication that would affect functional recovery, including neurotrophic substances[5-8] and drugs that may improve metabolism of the spinal cord.[9-11] Thus, any therapeutic effects were due to the surgery and rehabilitation.[12,13] To allow early mobilization, we used thin and light chest casts of quickset material (Polyurethane Foam GUKE Splint, Nanjing Chuniu Science LTD, China) made with posterior and anterior halves tailored to fit individual subject. For cervical injuries, a neck support was added. At postoperative day (dpo) 15, the patients were encouraged to stand and walk with the help of weight supporting devices under careful protection by the nurses. After 2 days (at dpo 17) a rehabilitation plan was designed for individual patient according to his or her standing and locomotion capability. The analysis terminated at 3 months after rehabilitation. The procedures used here were approved by the Institutional Review Board of the PLA Kunming General Hospital.

Locomotion scoring

We formulated a 10-grade Roman numeral locomotion scoring system, as shown in Figure 1. Grade I, the patient can not stand; grade II, the patient was able to stand with weight support and help in fixing the knee; grade III, the patient was able to stand with weight support; grade IV, the patient was able to walk with wheeled weight support and help in fixing the knee of the weight bearing leg; grade V, the patient was able to walk with wheeled weight support; grade VI, the patient was able to walk with the help of a light four-leg support; grade VII, the patient was able to walk with a pair of crutches; grade VIII, the patient was able to walk with a cane; grade IX, the patient was able to walk without support but staggeringly; and grade X, the patient was able to walk stably without support. Patients above grade VI no longer needed wheel chair weight support.

Statistical analysis

The patients were classified by the treatment groups (timing of surgery) and locomotor grades. The frequencies and proportions of locomotor grades in different treatment groups listed as frequency table and tested by Pearson chi-square. The level of statistical significance was set as P <0.05. All analysis were conducted with SPSS 11.0 (Chicago, USA).

RESULTS

Pathology of tissue debris removed from the spinal cord

In the early stages (e.g. 5 days after injury), there was profuse neurotrophilic infiltration and hemorrhage. Scattered activated microglia of different stages could be identified at the periphery (Figure 2A and 2B). At later stages (e.g. 2 weeks after injury), more advanced necrosis was evident (Figure 2C).

Functional recovery

The case histories of the 30 patients are summarized in Table 1. The analysis in this study was focused on the improvement of locomotion.

After a treatment for about three and a half months, all the patients were recovered to grade IV or above. There were 12 patients in grade IV, 2 in grade V, 3 in grade VI, 6 in grade VII, 2 in grade IX, and 5 in grade X. Thirteen patients (43.3%) were above VII. They were able to walk with a pair of crutches, a cane or to walk freely without any support. Figure 3 shows examples of patients of grade VIII and X.

Optimal operation time window

The distribution of the grade of locomotion is shown in Figure 4. The shortest period of days after operation (DAI) were 2 and the longest 65.

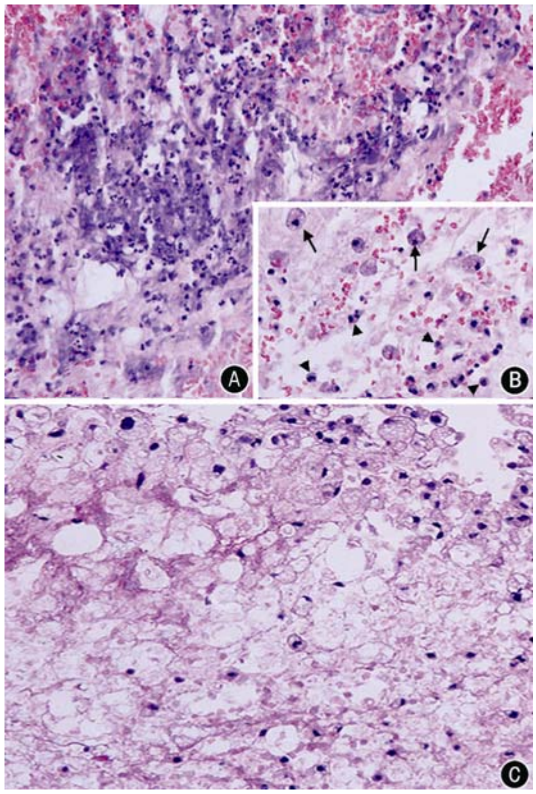

Figure 2. Pathology of the debris, HE staining. **A:** Five days after injury. Profuse neutrophilic infiltration and hemorrhage can be seen. **B:** Five days after injury. Many scattered early activated microglia can be identified (arrowheads), some show more advanced changes (arrows). **C:** Fourteen days after injury. The debris was necrotic and disintegrated. A large number of macrophages were present in the periphery (Original magnification ×400).

Based on the data shown in Figure 4, a Pearson chi-square statistic analysis was made to assess the relationship between timing of surgery and locomotor grades achieved. Table 2 shows the results of this analysis. Two groups were identified. The group A represents those treated within 4–14 days and B are those treated earlier than 4 days or later than 14 days. The statistical analysis indicated a statistically significant difference between patients treated within the 4–14 days after injury period and those treated at earlier or later time.

DISCUSSION

We chose to formulate a new locomotion grading system, rather than using other published scoring systems,[14-18] because this system represents stages of our rehabilitation program and devices that our subjects used. Furthermore, it is simple and reliable. As the patients progressed in their locomotor rehabilitation, their scores increased.

The idea of this neurosurgical intervention arose from the known pathology of secondary spinal cord injury. Necrosis in the spinal cord is a major cause of expanding secondary injury, which may finally reach a volume much

Table 1. Summary of case histories arranged in order of days after injury

Case No.	Sex	Age	Days after injury	Injured vert/sp cd	Injury type	Final locomotion grade	Final ASIA
1	M	32	2	L1/T12–L1	SC	IV	A
2	M	36	2	T11–T12/T11–L1	LC	V	A
3	M	32	2	T11–T12/T11–L1	LC	IV	A
4	M	25	3	T12–L1/T12–L1	SC	IV	C
5	M	34	3	C6/C5–C7	LC	IV	A
6	M	25	4	T7–T12/T8–T10	SC	X	D
7	M	44	4	T12–L1/T12–L1	SC	VI	A
8	M	43	4	T12–L1/T12–L1	LC	VII	C
9	M	28	4	L1/T11–L1	LC	VII	A
10	M	50	5	T12–L1/T11–L1	LC	IV	C
11	M	19	6	T12–L3/T11–L1	LC	X	D
12	M	45	7	T10–T11/T10–T12	LC	IV	A
13	M	33	10	T12–L2/T12–L1	MC	VI	A
14	M	54	10	C3–C6, T5/C3–C5	MC	VII	C
15	M	21	11	C3–C5/C2–C4	MC	X	D
16	F	32	11	T12–L1/T11–L1	SC	VII	A
17	M	25	12	T12–L2/T12–L1	MC	X	D
18	M	27	14	L2*/L1–L2	MC	VIII	C
19	M	35	15	T11–T12/T10–L1	SC	IV	A
20	M	31	18	L1–L2/T12–L1	MC	VI	C
21	M	19	18	T7–T12/T7–T12	SC	IV	A
22	F	24	19	T7–T8/T6–T8	SC	VII	A
23	M	26	22	C5–C6/C4–C7	MC	IV	B
24	M	42	23	L1/L1	SC	VII	C
25	M	38	25	C5/C3–C6	LC	IV	C
26	M	43	29	T5, T12–L1/T11–L1	SC	X	D
27	M	35	31	L1–L2/T12–L1	LC	V	A
28	F	34	34	T11–L1/T11–L1	LC	VIII	A
29	M	16	41	T12/T12–L1	LC	IV	A
30	M	24	65	C5–C6/C5–C7	SC	IV	A

All the patients were ASIA-A and locomotion grade I before operation. *The spinal cord of this patient extended to the lower level of L2. Vert: vertebra; sp cd: spinal cord; M: male; F: female; LC: lacerated contusion; SC: serious contusion; MC: mild contusion.

Figure 3. A: Walking with a pair of crutches (VIII), 3 months after operation. **B:** Walking without support (X), 3 months after operation. The electrodes attached on the legs were for electromyography.

Table 2. Statistical analysis of the distribution of locomotion grades

Groups	Grade scores		Total
	IV–V	>V	
A (*n* (%))	2 (15.4)	11 (84.6)	13 (100)
B (*n* (%))	12 (70.6)	5 (29.4)	17 (100)
Total	14 (46.7)	16 (53.3)	30 (100)

The percentages of grade score greater than grade V were 84.6% and 29.4% in group A and group B respectively. Pearson chi-square was 9.02 (P <0.01).

greater of the primary injury.[1-4] Early debridement should stop further expansion of the injury. It also serves as a form of intramedullary decompression, reducing the pressure on spared tissue. In most spinal contusions, a ring of spared white matter survives the injury.[19-21] Locomotion is controlled by a hierarchy of centers in the central nervous systems. Its major parts reside in areas of the brain stem from the basal ganglion down to the medulla oblongata, involving an intricate network of interneuronal connections. The final nuclei that project from the medulla oblongata to the spinal cord central pattern generators are the magnocellular reticular nucleus and the giagantocellular reticular nucleus.[22] Destruction of these descending fibers in spinal cord injury is the major cause of loss in locomotor function.[22,23] After spinal cord contusion, all the major locomotion centers in the brain are intact. The centers above and below the injury are physically connected by the spared fibers. If these spared

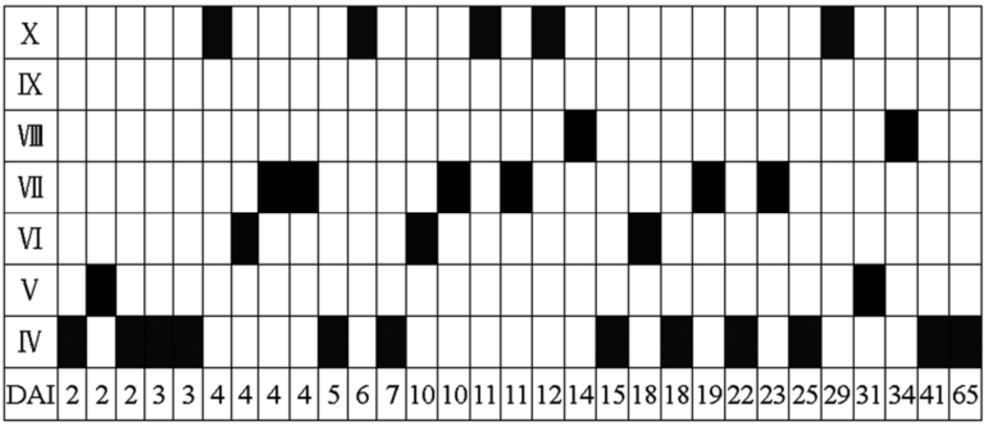

Figure 4. Distribution of locomotion grades. All of the 30 patients had recovered to grade IV or above. Cases above grade VI were those who could walk without the help of wheeled chair support. There were 16 cases above VI, 11 were clustered between 4–14 days after injury. Besides, there were only 2 IVs in the group between 4–14 days after injury. Thus, 4–14 DAI appears to be an optimal operation time window.

fibers are compressed by the expanding necrosis, loss of locomotor function may occur. People with ASIA-A spinal cord injuries usually show loss of locomotion and sensory activities down to the peri-anal region. Early surgical intervention that include separation of the arachnoid adhesions to resume patent CSF flow and debridement, should cut short the process of expanding secondary injury and reduce the intramedullar pressure on the spared fibers. Therefore, such surgery may enhance better recovery of spared fibers. Our results suggest that such surgery have dramatic effects on walking recovery. Patients that are ASIA-A or motor "complete" spinal cord injury seldom recover independent locomotion,[24] even with extensive treadmill-based weight-supported gait training[25] and even prolonged training, combined with functional electrical stimulation.[26]

The identification of an optimal operation time window at 4 to 14 days after injury has practical implication. Under normal circumstances, it provides sufficient time for spinal-injured patient to be transferred from the site of accident to a qualified hospital for the operation.

In conclusion, the present study demonstrates that early neurosurgical intervention shortly after orthopedic stabilization of the spinal cord and early rehabilitation of a spinal cord contusion can lead to dramatic improvements of locomotor activity. It is a novel therapeutic approach for spinal cord contusion. There are many important aspects of spinal cord contusion other than locomotion that need to be analyzed. This should be studied with a larger collection of clinical cases.

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