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Original Article

Neurological Analysis Based on the Terminal End of the Spinal Cord and the Narrowest Level of Injured Spine in Thoracolumbar Spinal Injuries

Yuji Hatakeyama[a]*, Michio Hongo[b], Tadato Kido[c], Masakazu Urayama[d], Yuji Kasukawa[b], Hiroshi Sasaki[e], Toshiaki Aizawa[f], Daisuke Kudo[b], Ryota Kimura[b], Yuichi Ono[a], Fumihito Kasama[b], and Naohisa Miyakoshi[b]

*[a]Department of Orthopaedic Surgery, Akita Red Cross Hospital, Akita 010-1495, Japan,
[b]Department of Orthopaedic Surgery, Akita University Graduate School of Medicine, Akita 010-8543, Japan,
[c]Department of Orthopaedic Surgery, Akita Rosai Hospital, Odate, Akita 018-5604, Japan,
[d]Department of Orthopaedic Surgery, Ogachi Central Hospital, Yuzawa, Akita 012-0055, Japan,
[e]Department of Orthopaedic Surgery, Noshiro Kousei Medical Center, Noshiro, Akita 016-0014, Japan,
[f]Department of Orthopaedic Surgery, Kitaakita Municipal Hospital, Kitaakita, Akita 018-4221, Japan*

This study aimed to clarify neurological differences among the epiconus, conus medullaris, and cauda equina syndromes. Eighty-seven patients who underwent surgery for acute thoracolumbar spinal injuries were assessed. We defined the epiconus as the region from the terminal end of the spinal cord to the proximal 1.0 to 2.25 vertebral bodies, the conus medullaris as the region proximal to < 1.0 vertebral bodies, and the cauda equina as the distal part of the nerve roots originating from the spinal cord. On the basis of the distance from the terminal end of the spinal cord to the narrowest level of the spinal canal, the narrowest levels were ordered as follows: the epiconus followed by the conus medullaris and cauda equina. The narrowest levels were the epiconus in 22 patients, conus medullaris in 37 patients, and cauda equina in 25 patients. On admission, significantly more patients had a narrowed epiconus of Frankel grades A-C than a narrowed cauda equina. At the final follow-up, there were no significant differences in neurological recovery among those with epiconus, conus medullaris, or cauda equina syndrome. Anatomically classifying the narrowest lesion is useful for clarifying the differences and similarities among these three syndromes.

Key words: thoracolumbar spinal injury, terminal end of spinal cord, conus medullaris, epiconus syndrome, cauda equina syndrome

Thoracolumbar spinal injuries may anatomically result in epiconus, conus medullaris, and/or cauda equina syndromes [1-6]. However, the coexistence of all three of these spinal cord structures can make it difficult to determine the neurological symptoms associated with thoracolumbar spinal injury [7]. Although it has been reported that the terminal end levels of the spinal cord exhibit wide variation among patients at the anatomical level [7], neurological evaluations have typically been performed according to the level of the injured vertebra [2,4,8,9]. Therefore, by initially identifying the terminal end level of the spinal cord and defining the ranges of the epiconus, conus medullaris, and cauda equina for the individual patient, rather than using the vertebral level as a relative measure, it may be possible to evaluate lesions caused by an injured vertebra more thoroughly, and thereby interpret

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*Corresponding author. Phone : +81-18-829-5000; Fax : +81-18-829-5255
E-mail : yuji_hatakeyama@akita-med.jcr.or.jp (Y. Hatakeyama)

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neurological symptoms more precisely.

The aims of this study were to investigate the anatomical relationships between the narrowest level of the injured spine and the ranges of the epiconus, conus medullaris, and cauda equina, and to clarify the neurological differences between the epiconus, conus medullaris, and cauda equina syndromes.

Materials and Methods

This study was conducted retrospectively with the approval of the Ethics Committee of the authors' affiliated hospital (approval code: No. 389). Additionally, the study complied with the principles of the World Medical Association's Declaration of Helsinki. All patients signed consent forms.

Eighty-seven patients (59 men and 28 women) who underwent surgery for acute thoracolumbar (T11-L2) spinal injuries at our institution from 2009 to 2019 were assessed. Their mean age was 56.5 ± 15.8 years, and the mean period from injury to surgery was 12.1 ± 11.1 days. The inclusion criteria were as follows: acute thoracolumbar burst fracture, dislocation fracture, and flexion–distraction injury. Preoperative X-ray, computed tomography, and magnetic resonance imaging were performed to determine surgical indications. Surgical decompression was added to spinal fusion for patients with muscle weakness of the lower extremity and/or bowel and bladder dysfunction, or with radiologically moderate to severe spinal canal compromise. Fifty-two patients underwent spinal fusion only, and the remaining 35 underwent decompression and fusion. The mean follow-up period was 60.5 ± 36.6 months.

The terminal end level of the spinal cord was evaluated using sagittal- and axial-plane images obtained preoperatively by T2-weighted magnetic resonance imaging. A perpendicular line to the long axis of the spinal cord was used to locate the terminal end of the spinal cord and to define the relationship with the adjacent vertebrae. Each vertebral body was divided into thirds [upper (U), middle (M), and lower (L)], and the intervertebral disc space was defined as a separate region. This classification method was used in several previous studies [10-12], and its reliability was 0.995 (intraclass correlation coefficient) [12]. For statistical analyses, spinal levels represented numerical values ranging from 1 (lower third of L2) to 11 (upper third of T12) for the termination of the spinal cord. The level of the spinal canal space most narrowed by injury was assessed using axial-plane computed tomographic images obtained preoperatively. The percentage of spinal canal compromise was calculated by dividing the area of intrusion by the total spinal canal area multiplied by 100 [13]. An anatomical study by Toribatake *et al.* [14] reported that the primary lesion of epiconus syndrome with radicular sensory disturbance was generally located from 1.0 to 2.25 vertebrae and was 1.6 vertebral bodies proximal to the terminal end of the spinal cord. Considering their anatomical findings, we defined the epiconus as the region from the terminal end of the spinal cord to the proximal 1.0 to 2.25 vertebral bodies, the conus medullaris as the region proximal to < 1.0 vertebral bodies, and the cauda equina as the distal part of the nerve roots originating from the spinal cord. We measured the distance from the terminal end of the spinal cord to the narrowest point of the spinal canal in each patient, and found that the narrowest levels occurred in the following order: epiconus, conus medullaris, and cauda equina. We also evaluated a high signal intensity area of the injury level by T2-weighted sagittal magnetic resonance imaging, because there was a possibility that lesions related to the most severe spinal cord injury did not always match the site with the narrowest vertebral body (Fig. 1).

The neurological findings for each patient were assessed on admission and at the final follow-up examination according to the Frankel grade [15] and a manual muscle test (MMT) of the lower extremities. The patients were divided into the following groups: motor-useless Frankel grades A to C (group S) and motor-useful Frankel grades D and E (group M).

Statistical analysis. Statistical analysis was performed using StatView Version 5.0® (SAS Institute, Cary, NC, USA). Between-group comparisons were performed using the Mann-Whitney *U*-test and Fisher's exact probability test. With the narrowest level (epiconus, conus medullaris, or cauda equina) as a grouping factor and the Frankel grade on admission (groups S and M) as a within-subject factor, a two-way factorial analysis of variance was performed. For statistical analyses of neurological recovery, the Frankel grades were determined as numerical values ranging from 1 (Frankel A) to 5 (Frankel E). With the Frankel grades on admission and at the final follow-up as within-subject factors, a two-way repeated-measures analysis of variance was used. Statistical significance was set at $p < 0.05$.

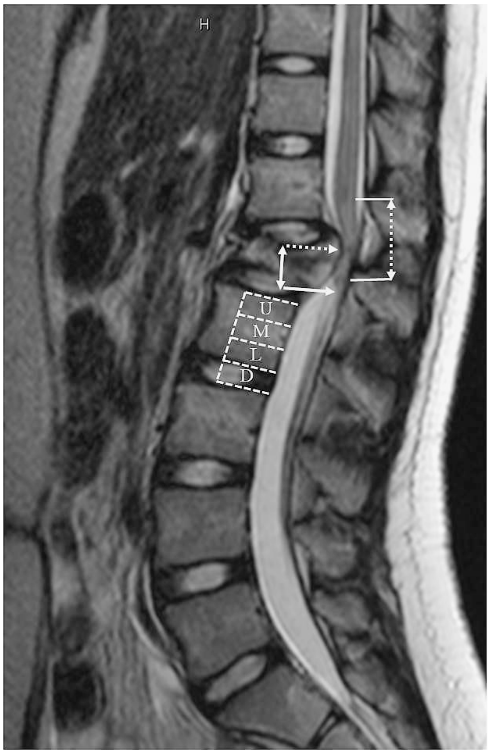

Fig. 1 The interval from the terminal end of the spinal cord to the narrowest level of the spinal canal was measured. The narrowest level of the spinal canal was ordered according to the interval as follows: epiconus, conus medullaris, and cauda equina. Solid single arrow: terminal end of the spinal cord. Dotted single arrow: the narrowest level of the spinal canal. Solid double-headed arrow: the interval from the terminal end of the spinal cord to the narrowest level. Dotted double-headed arrow: high T2-weighted signal intensity area. U, upper third of the vertebral body; M, middle third; L, lower third; D, disc.

Results

The most common terminal end level of the spinal cord was the middle third of L1 (31.0%; 27 patients) followed by the upper third of L1 (18.4%; 16 patients) (Table 1). The mean position of the terminal end of the spinal cord was 5.37 (between the middle and lower third of L1) for men and women (5.35 for men; 5.42 for women). No significant difference in the terminal end level of the spinal cord was observed between men and women.

The narrowest level of the spinal canal was generally located at the upper third of L1 (21.8%; 19 patients) followed by the middle third of L1 (20.7%; 18 patients) and the upper third of L2 (17.2%; 15 patients) (Table 2). Three patients had no narrowing of the canal at the thoracolumbar junction. The mean interval from the terminal end of the spinal cord to the narrowest portion of the spinal canal was 0.3 ± 0.8 vertebral bodies.

Table 1 Frequency distribution for the terminal end level of the spinal cord

Terminal end level	N = 87
T12 middle 1/3	1 (1.15%)
T12 lower 1/3	1 (1.15%)
T12/L1	3 (3.45%)
L1 upper 1/3	16 (18.40%)
L1 middle 1/3	27 (31.00%)
L1 lower 1/3	14 (16.10%)
L1/L2	13 (14.90%)
L2 upper 1/3	7 (8.05%)
L2 middle 1/3	3 (3.45%)
L2 lower 1/3	2 (2.30%)

Table 2 Frequency of the narrowest level of the spinal canal among the patients

Most narrowed level	N = 84
T10/11	1 (1.15%)
T11 upper 1/3	1 (1.15%)
T11 middle 1/3	2 (2.30%)
T11 lower 1/3	2 (2.30%)
T11/12	1 (1.15%)
T12 upper 1/3	6 (6.90%)
T12 middle 1/3	7 (8.05%)
T12 lower 1/3	1 (1.15%)
L1 upper 1/3	19 (21.80%)
L1 middle 1/3	18 (20.70%)
L1 lower 1/3	6 (6.90%)
L1/2	1 (1.15%)
L2 upper 1/3	15 (17.20%)
L2 middle 1/3	4 (4.60%)

According to this interval, the narrowest levels were in the following order: the epiconus, with a mean interval of 1.5±0.4 vertebral body in 22 patients; the conus medullaris, with a mean interval of 0.3±0.3 vertebral body in 37 patients; and the cauda equina, with a mean interval of −0.5±0.3 vertebral body in 25 patients.

The whole mean percent spinal canal compromise was 32.8±18.7% preoperatively (narrowed epiconus =29.3%, narrowed conus medullaris=36.7%, narrowed cauda equina=30.5%) and 15.7±15.1% postoperatively (narrowed epiconus=12.9%, narrowed conus medullaris=19.2%, narrowed cauda equina=14.3%). No significant difference was found among the three groups either before or operation. The mean percent spinal canal compromise of patients with muscle weakness (Frankel A-D) was significantly larger than that in those without muscle weakness (Frankel E) ($p<0.05$). The mean percent spinal canal compromise of patients with both narrowed epiconus and conus medullaris together with bowel bladder dysfunction was significantly larger than that of such patients without bowel bladder dysfunction ($p<0.05$). The preoperative mean percent spinal canal compromise of patients who had undergone spinal fusion and decompression was significantly larger than that of those who received only spinal fusion (44.5% vs 23.8%, respectively; $p<0.0001$; Table 3).

Figure 2 shows the Frankel grade on admission. Three patients were grade A, 3 were grade B, 8 were grade C, 19 were grade D, and 51 were grade E. In group S, significantly more patients had a narrowed epiconus than a narrowed cauda equina, and significantly more patients in group M had a narrowed cauda equina than a narrowed epiconus ($p=0.0400$). In group S, 11 patients underwent spinal fusion and decompression, and 3 received only spinal fusion ($p=0.0178$). At the final follow-up, 3 patients were grade A, 1 was grade C, 13 were grade D, and 67 were grade E (Fig. 3).

Twenty-one patients (narrowed epiconus: 6; narrowed conus medullaris: 10; narrowed cauda equina: 5) showed high T2-weighted signal intensity by magnetic resonance imaging (Table 4). Two patients with a narrowed epiconus had high signal intensity from the epiconus to the conus medullaris. Two patients with a narrowed conus medullaris had it from the epiconus to the cauda equina, 5 patients with a narrowed conus medullaris had it from the conus medullaris to epiconus, and 1 patient had it from the conus medullaris to the cauda equina. Two patients with a narrowed cauda equina had it from the cauda equina to the conus medullaris. In 6 patients, the high T2-weighted signal intensity area did not include the narrowest level.

Figure 4 shows the average MMT of patients with muscle weakness on admission. In the narrowed epiconus, the average MMT was significantly smaller than those of the narrowed conus medullaris and cauda equina ($p<0.01$). In the narrowed conus medullaris, there was a trend toward decreasing tibialis anterior, extensor hallucis longus, calf (gastrocnemius and soleus), and peroneus as compared to iliopsoas and quadriceps. Especially, the peroneus was significantly smaller than the iliopsoas and quadriceps ($p=0.04$). Figure 5 reveals

Table 3 Preoperative spinal canal compromise

	Epiconus (%)	Conus medullaris (%)	Cauda equina (%)
Frankel A-E	29.3±22.0	36.7±16.4	30.5±18.6
Frankel A-D/E	44.2±27.7*/20.4±12.1	46.0±12.8*/29.4±15.5	40.5±16.1*/24.1±17.7
Bowel/bladder dysfunction +/−	59.4±21.1⁑/22.4±15.9	58.2±13.1⁑/33.3±14.2	54.9±18.7/26.9±16.0
Operative procedure Fusion/Fusion+decompression		23.8±14.8/44.5±16.8#	

Values: mean±SD.
* The mean percent spinal canal compromise of patients with muscle weakness (Frankel A-D) was significantly larger than those without muscle weakness (Frankel E) ($p<0.05$).
⁑ The mean percent spinal canal compromise of patients with narrowed epiconus and conus medullaris with bowel bladder dysfunction was significantly larger than those without bowel bladder dysfunction ($p<0.05$).
The mean percent spinal canal compromise of patients who underwent spinal fusion and decompression was significantly larger than that of those who received only spinal fusion ($p<0.0001$).

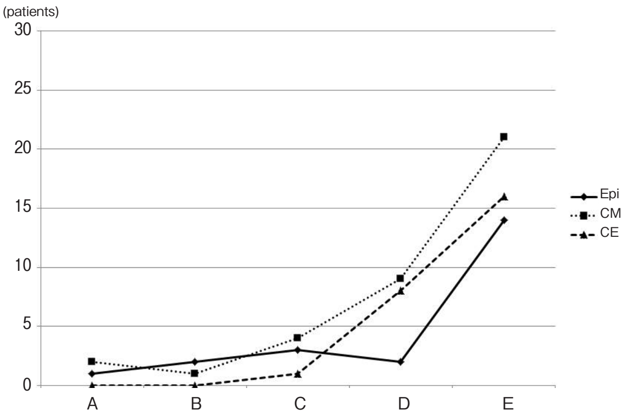

Fig. 2 Frankel grade on admission. Epi, the narrowest level was at the epiconus; CM, conus medullaris; CE, cauda equina.

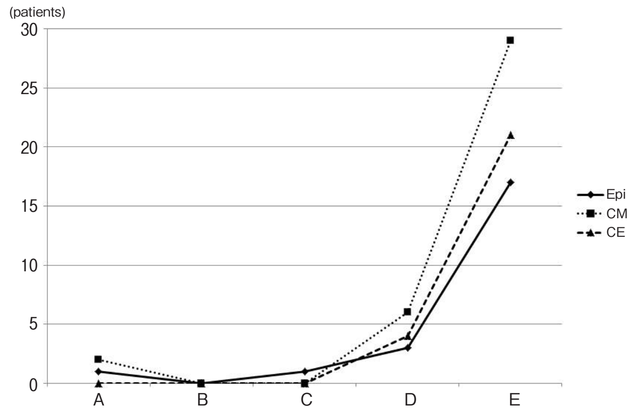

Fig. 3 Frankel grade at final follow-up. Epi, the narrowest level was at the epiconus; CM, conus medullaris; CE, cauda equina.

the average MMT of patients with muscle weakness at the final follow-up. In the narrowed epiconus, the average MMT was significantly smaller than those in the narrowed conus medullaris and cauda equina ($p < 0.01$).

Table 5 shows the neurological recovery of patients with a narrowed epiconus, conus medullaris, and cauda equina. The Frankel grades were significantly improved at the final follow-up compared with those at admission ($p < 0.0001$). However, there were no significant differences in Frankel grade between those with a narrowed epiconus, conus medullaris, and cauda equina at final follow-up. Patients with a narrowed epiconus, except for those that were Frankel E grade on admission, showed neurological improvement of at least one Frankel grade (87.5%) compared with patients with a narrowed conus medullaris (75.0%) and those with a narrowed cauda equina (66.7%).

Table 6 shows the data of 11 patients who had bowel and bladder dysfunction on admission. Three patients had a narrowed epiconus, 5 had a narrowed conus medullaris, and 3 had a narrowed cauda equina. The 5 patients with a narrowed conus medullaris had muscle weakness of the lower extremities (Frankel grades A-D). At the final follow-up, 2 patients showed improvement and 9 patients remained unchanged.

Discussion

The range of the terminal end of the spinal cord was reported to be T12-L3 [16, 17] in cadaveric studies and T11-L3 [11] or T11/12-L3 [10] in studies using magnetic resonance imaging. The mean position of the terminal end of the spinal cord was the middle third of L1 [11], the lower third of L1 [16], and the upper third of L2 [17]. In the present study, the terminal end levels of the spinal cord varied from the middle third of T12 to the lower third of L2. The most common terminal end level of the spinal cord was the middle third of L1 (31.00%), followed by the upper third of L1 (18.40%). In approximately 66% of patients, the terminal end of the spinal cord was located at L1. This wide variation in the position of the terminal end of the spinal cord is in accordance with previous reports [10, 11, 16, 17]. This indicates that the spinal cord terminated at a level other than L1 in the remaining 34% of patients.

Thompson [16] reported that women have a lower terminal end level of the spinal cord than men. However, our present results agreed with those of [Macdonald *et al.*], who found no significant difference between men and women in terms of the lower terminal end level of the spinal cord [11]. Therefore, further investigation is needed to more definitively identify any potential differences.

The narrowest level of the spinal canal was generally situated at the upper and middle thirds of L1 (21.80% and 20.70%, respectively), followed by the upper third of L2 (17.20%) and the middle and upper thirds of T12 (8.05% and 6.90%, respectively). These results suggest that the upper vertebral body was the main location of the injury. Denis [18] reported that type B fractures (fracture of the superior endplate) were the most frequent burst fractured at the thoracolumbar junction. Kim *et al.* [9] stated that Denis type B fractures were the most common burst fractures in the thoracolumbar

Table 4 Twenty-one patients who showed high T2-weighted signal intensity by magnetic resonance imaging

Case	Age (ys)/Sex	Terminal end of spinal cord	The most narrowed level	Interval (vertebral body)	The most narrowed lesion	T2 high signal intensity area	Frankel grade		Bowel and bladder dysfunction
							On admission	AT the final	
1)	55/Female	L1: U	T12: U	1	Epiconus	T11: U-L1 U: Epiconus – Conus medullaris	B	D	−
2)	63/Male	L2: U	L1: U	1	Epiconus	L1: U-L1 L: Epiconus –Conus medullaris	C	D	+
3)	56/Male	L1: U	T10/11: D	2.25	Epiconus	T10-T11: D: Epiconus	A	A	+
4)	72/Female	L1: M	T11/12: D	1.5	Epiconus	T11: M-T12: U: Epiconus	C	D	−
5)	67/Male	L1: M	T11: L	1.75	Epiconus	T11: U-T11: L: Epiconus	E	E	−
6)	46/Male	L1: M	T12: U	1.25	Epiconus	T11: M-T12: U: Epiconus	B	C	+
7)	81/Female	L1: M	L1: M	0	Conus medullaris	T12: M-L1: L: Epiconus – Cauda equina	D	E	−
8)	52/Female	L2: U	L1: M	0.75	Conus medullaris	L1: U-L1: L: Epiconus – Conus medullaris	C	D	−
9)	51/Male	L1: M	L1: U	0.25	Conus medullaris	T12: M-L1: L: Epiconus – Cauda equina	C	D	+
10)	14/Female	L1/L2: D	L1: U	0.75	Conus medullaris	T12: L-L1: M: Epiconus – Conus medullaris	C	D	+
11)	44/Male	L1: L	L1: U	0.25	Conus medullaris	T12: U-L1: L: Epiconus – Conus medullaris	A	A	+
12)	75/Male	L1: M	T12: L	0.75	Conus medullaris	T12: U-T12: L: Epiconus – Conus medullaris	A	A	+
13)	57/Female	L1/2: D	L1: M	0.5	Conus medullaris	L1: M: Conus medullaris	D	E	+
14)	42/Male	L1/2: D	L1: M*	0.5	Conus medullaris	T12/L1: D*: Epiconus – Conus medullaris	B	D	−
15)	78/Male	L2: U	L2: U*	0	Conus medullaris	L1: L*: Conus medullaris	D	E	−
16)	63/Female	L1: U	T12: M*	0.75	Conus medullaris	L1: M-L1: L*: Conus Medullaris – Cauda equina	D	E	−
17)	69/Male	L1: M	L1: L	−0.25	Cauda equina	L1: M-L1: L: Conus Medullaris – Cauda equina	D	E	+
18)	50/Male	T12: M	L1: M	−1	Cauda equina	T12: L-L1: L: Cauda equina	E	E	−
19)	64/Male	L1: M	L2: M*	−1	Cauda equina	L1: M-L1: L*: Conus Medullaris – Cauda equina	E	E	−
20)	41/Male	T12: L	L2: U*	−1.5	Cauda equina	L1: U-L1: L*: Cauda equina	D	E	−
21)	40/Male	L1: L	L2: U*	−0.5	Cauda equina	L1: L*: Cauda equina	C	D	+

U, upper 1/3 of vertebral body; M, middle 1/3; L, lower1/3; D, disc; *, T2-weighted high signal intensity area did not include the most narrowed level.

spine. The morphology of vertebral fractures in the present study was similar to that previously reported.

To thoroughly evaluate lesions caused by an injured vertebra in thoracolumbar spinal injuries and interpret neurological symptoms, the vertebral level should not be used as a relative measure; rather, the terminal end level of the spinal cord should be determined initially and the ranges of the epiconus, conus medullaris, and cauda equina should be defined for each case. Considering the anatomical findings reported by Toribatake *et al.*, we defined the epiconus as the region from the terminal end of the spinal cord to the proximal 1.0 to 2.25 vertebral bodies, the conus medullaris as proximal to < 1.0 vertebral bodies, and the cauda equina as the distal part of the nerve roots originating from the spinal cord. Asada *et al.* [19] evaluated 19 patients with chronic thoracolumbar spinal lesions and classified them into four syndromes — thoracic myelopathy, epiconus, conus medullaris, and cauda equina — based on their symptoms, including myelopathy with hyperreflexia in the lower leg; epiconus syndrome with paresis and radicular pain and decreased reflex; conus medullaris syndrome with bowel bladder dysfunction before severe leg pain or paresis; and cauda equina syndrome with bilateral radicular pain aggravated by walking. In that study, of the patients with epiconus syndrome the distance from the lesion was from 1 to 2 vertebral bodies proximal to where the spinal cord terminated. Of the patients with conus medullaris syn-

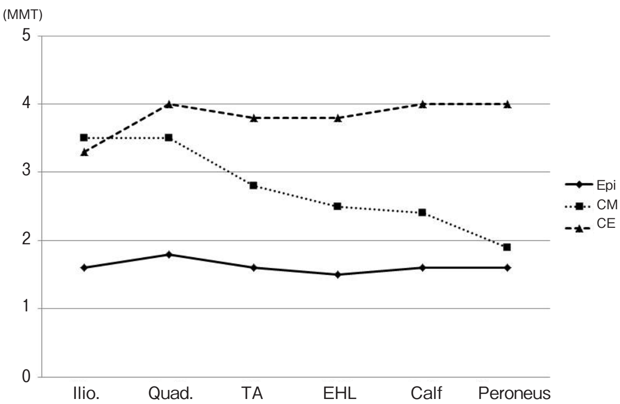

Fig. 4 Average MMT of patients with Frankel grades A-D on admission. Epi, the narrowest level was the epiconus; CM, conus medullaris; CE, cauda equina; MMT, manual muscle test; Ilio., iliopsoas; Quad., quadriceps; TA, tibialis anterior; EHL, extensor hallucis longus; Calf, gastrocnemius and soleus. In the narrowed epiconus, the average MMT was significantly smaller than those of the narrowed conus medullaris and cauda equina ($p < 0.01$). In the narrowed conus medullaris, there was a trend toward tibialis anterior, extensor hallucis longus, calf (gastrocnemius and soleus), and peroneus decreasing compared to iliopsoas and quadriceps. Especially, Peroneus was significantly smaller than iliopsoas and quadriceps ($p = 0.04$).

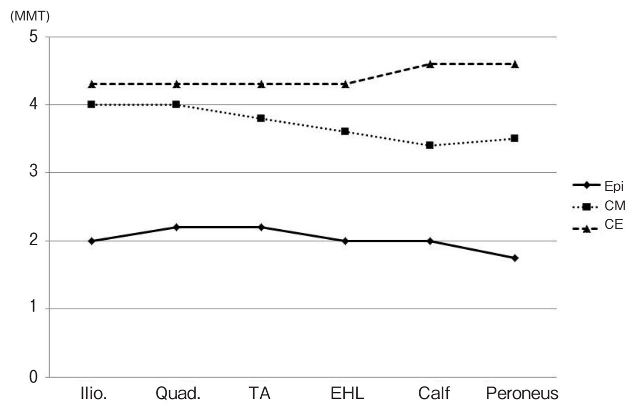

Fig. 5 Average MMT of patients with Frankel grades A-D at the final follow-up. Epi, the narrowest level was the epiconus; CM, conus medullaris; CE, cauda equina; MMT, manual muscle test; Ilio., iliopsoas; Quad., quadriceps; TA, tibialis anterior; EHL, extensor hallucis longus; Calf, gastrocnemius and soleus. In the narrowed epiconus, the average MMT was significantly smaller than those of the narrowed conus medullaris and cauda equina ($p < 0.01$).

Table 5 Neurological recovery of the patients with a narrowed epiconus, conus medullaris, and cauda equina

The most narrowed level	On admission	At the final	*P*-value (most narrowed level)	*P*-value (recovery rate)
Epiconus	2.750 ± 1.035	3.875 ± 1.356		
Conus medullaris	3.250 ± 1.065	4.250 ± 1.065	0.149	< 0.0001
Cauda equina	3.889 ± 0.333	4.556 ± 0.527		

Values: mean ± SD.

Table 6 Eleven patients who had bowel and bladder dysfunction on admission

Case	The most narrowed level	Age (ys)	From injury to ope (days)	Spinal canal compromise (%)	Frankel grade		Bowel/bladder dysfunction at the final
					on admission	at the final	
1	Epiconus	56	14	77.2	A	A	unchanged
2	Epiconus	63	7	36.1	C	D	unchanged
3	Epiconus	46	5	64.9	B	C	unchanged
4	Conus Medullaris	57	28	37.2	D	E	improved
5	Conus Medullaris	51	5	60.9	C	D	unchanged
6	Conus Medullaris	14	0	55.3	C	D	unchanged
7	Conus Medullaris	44	7	68.5	A	A	unchanged
8	Conus Medullaris	75	11	69.4	A	A	unchanged
9	Cauda Equina	69	11	34.2	D	E	improved
10	Cauda Equina	53	7	59.9	D	D	unchanged
11	Cauda Equina	40	11	70.6	C	D	unchanged

drome, the distance from the lesion was from −0.25 to 0.75 vertebral bodies. These results are comparable to our definitions and support the validity of the present study.

On admission, significantly more patients in group S had a narrowed epiconus compared with a narrowed cauda equina. The preoperative mean percentage of spinal canal compromise was 29.3% in patients with a narrowed epiconus and 30.5% in those with a narrowed cauda equina. Hashimoto *et al.* [20] reported that a small bony fragment in the spinal canal resulted in a higher incidence of neural damage at the epiconus level than at the cauda equina level. The results of the present study are in accordance with that report. Anatomically, the epiconus comprises the cord segment between L4 and S1 [14, 20]. Regarding the morphologic features of cross sections of the lumbosacral segments, the anterior horns increase and expand anterolaterally [21]. Therefore, lower motor neuron disorders in the anterior horn can be easily caused by the dynamic compression of thoracolumbar spinal injuries. These anatomical characteristics may affect the muscle weakness of those with a narrowed epiconus.

On admission, there was no significant difference between the number of patients in group S with a narrowed conus medullaris and the number with a narrowed epiconus. The conus medullaris consists of the cord segment between S2 and S5 [14, 23]. Conus medullaris syndrome is mainly characterized by bowel bladder dysfunction, usually accompanied by some motor and sensory symptoms involving the lower extremities. In the present study, the preoperative mean percentages of spinal canal compromise in patients with or without muscle weakness with a narrowed conus medullaris were 46.0% and 29.4%, respectively ($p < 0.05$). Regarding the cross-sectional anatomy at the level of the conus medullaris in human cadavers, Wall *et al.* [24] reported that the nerve roots formed a peripheral rim around the spinal cord and that most cephalad roots lay laterally, whereas more caudal roots overlapped toward the midline. In this study, we observed a decrease in the activity of the extensor hallucis longus, calf (gastrocnemius and soleus), and peroneus muscles in individuals with a narrowed conus medullaris. These muscles are innervated by the L5 and S1 nerve roots. Peroneus, an S1 innervated muscle, was significantly smaller than iliopsoas and quadriceps, which were L2, L3, and L4 innervated muscles. This result suggests that more caudal roots are susceptible to damage. Therefore, it is possible that a high percentage of spinal canal compromise as well as this anatomical specificity might cause the muscle weakness of patients with a narrowed conus medullaris.

There was a trend toward fewer patients in group S having narrowed cauda equina on admission and at the final evaluation; however, there was no significant difference in neurological severity between the patients with a narrowed cauda equina and those with a narrowed conus medullaris. Regarding the difficulty in differentiating between syndromes, Podnar [25] reported that neurological outcomes could not be used to differentiate between conus medullaris and cauda equina syndromes, because additional spinal root lesions could not be excluded in 20 patients with conus medullaris lesions. They used the vertebral level as a relative measure at the T12 or L1 level for conus medullaris lesions and segments at the L2 to L5-S1 levels for cauda equina. In the present study, we identified the terminal end level of the spinal cord and defined the ranges of epiconus, conus medullaris, and cauda equina for each case. We think the evaluation in the current study is more anatomical than the use of the vertebral level as a relative measure. However, further investigation is needed to clarify these differences and similarities between the conus medullaris and cauda equina syndromes.

Harrop *et al.* [8] reported the potential of anatomic regions for neurologic improvement: 48.2% for the thoracolumbar region (T10 to T12) and 84.5% for the lumbar region. The "transition zone" segments, T10 to T12, demonstrated significantly less neurologic improvement than injured lumbar spinal cord. In the present study, however, patients with a narrowed epiconus, conus medullaris, or cauda equine had a neurological improvement rate of 87.5%, 75.0%, or 66.7%, respectively. The extent of neurological recovery did not differ significantly between patients with epiconus, conus medullaris, and cauda equina syndromes. This is in contrast with the results reported by Harrop *et al.* In their study, 17 of 26 patients with injury in the thoracolumbar region were American Spinal Injury Association (ASIA) grade A and showed 7.7% neurological improvement. The thoracolumbar region was defined as T10 to T12 using the vertebral level as a relative measure. Therefore, the thoracic region might coexist with epiconus and conus medullaris syndromes. These two factors might affect differences in neurological recovery. Few studies have compared neurological improvement between patients with a narrowed epiconus, conus medullaris, and cauda equina by identifying the terminal end level of the spinal cord and defining the ranges of the epiconus, conus medullaris, and cauda equina for each case. The present results suggest that the extent of neurological recovery might not differ significantly between patients with epiconus, conus medullaris, and cauda equina, and that severity on admission might persist to the final evaluation. These factors might be useful for predicting prognoses.

On admission, 5 patients with conus medullaris had bowel and bladder dysfunction. At the final follow-up, 1 of the 5 had improved and the remaining 4 were unchanged. The recovery rate (20.0%) was lower than in previous reports (20.9-72.7%) [1,3,5,6,26,27]. In previous studies that did not consider the anatomical level of the terminal end of the spinal cord, a neurological lesion was defined as a spinal cord injury if the fracture was at the T10 level or above, as conus medullaris syndrome if the fracture was at T11-L1, and as cauda equina injury if the fracture was at the L2 level or below. Therefore, the previous studies might have mixed epiconus, conus medullaris, and cauda equina syndromes.

The mean preoperative percentages of spinal canal compromise in patients with bowel and bladder dysfunction with conus medullaris and cauda equina syndromes were 58.2% and 54.9%, respectively. We found that 37.2% and 34.2% of patients (patients 4 and 9) with conus medullaris and cauda equina syndromes, respectively, had improved bowel and bladder dysfunction, and 2 patients were Frankel grade D on admission. This suggests that bowel and bladder dysfunction in patients with a low percentage of spinal canal compromise and Frankel grade D have the potential to improve.

Typical conus medullaris syndrome (pure conus syndrome) is relatively rare because of the transitional anatomy of the thoracolumbar lesion [28]. All 5 patients with a narrowed conus medullaris who had bowel and bladder dysfunction showed muscle weakness in the lower extremities. Clohisy *et al.* [26] reported 20 patients with incomplete neurologic deficits after thoracolumbar junction fractures. They stated that all 15 patients with conus medullaris syndrome had impairment in the lower limbs. Thus, the present study supports the idea that pure conus medullaris syndrome without muscle weakness in the lower extremities is rare.

Twenty-one patients showed high T2-weighted signal intensity by magnetic resonance imaging. Two patients with a narrowed epiconus had high signal intensity from the epiconus to the conus medullaris, and 7 patients with a narrowed conus medullaris had it from the conus medullaris to the epiconus. One person with a narrowed epiconus had bowel and bladder dysfunction. The average MMT of 7 patients with a narrowed conus medullaris were iliopsoas, 2.8; quadriceps, 2.9; tibialis anterior, 1.3; extensor hallucis longus, 0.7; and calf (gastrocnemius and soleus), 0.3. Therefore, 8 patients (1 with a narrowed epiconus and 7 with a narrowed conus medullaris) might have combined lesions of the epiconus and conus medullaris. Two patients with a narrowed cauda equina had high T2-weighted signal intensity from the cauda equina to the conus medullaris. One person had bowel and bladder dysfunction. This result suggests there was a possibility that 1 patient with a narrowed cauda equina had combined lesions of the conus medullaris and cauda equina. In 6 patients, the high T2-weighted signal intensity areas did not include the most narrowed level. Therefore, in these patients, lesions related to the most severe spinal cord injury may not have matched the site with the narrowest vertebral body.

Limitations. This study had several limitations. First, in some cases we could not identify the anatomical locations of the epiconus, conus medullaris, and cauda equina. At present, it is difficult to determine these anatomical levels radiologically and surgically. However, it is useful to diagnose the level of the spinal cord injury relative to the spinal cord termination. Using this system, we could perform a preliminary diagnosis regarding whether the injured lesion was in the epiconus, conus medullaris, or cauda equina and thus determine a more accurate prognosis for the recovery of neurological symptoms. Second, because the present study was a retrospective evaluation, it did not evaluate saddle anesthesia or anal problems, which are important findings for conus medullaris syndrome, in all patients. This might have resulted in an underestimation of conus medullaris syndrome. Third, lesions related to the most severe spinal cord injury do not always match the site with the narrowest vertebral body. Eight patients might have had combined lesions of the epiconus and conus medullaris and 1 patient might have had combined lesions of the conus medullaris and cauda equina. In 6 patients, the high T2-weighted signal intensity area did not include the narrowest level. We assumed that the narrowest site of the vertebral body was where the most severe lesions were located after spinal cord injury. Despite these limitations, the findings of this study should have significant clinical implications and will aid our understanding of neurological findings related to thoracolumbar spinal injuries.

In conclusion, we performed a preliminary diagnosis to determine whether the injured spinal cord level was at the epiconus, conus medullaris, or cauda equina. On admission, significantly more patients had a narrowed epiconus and Frankel grades A to C than had a narrowed cauda equina. At the final follow-up, there were no significant differences in the neurological recovery of patients with epiconus, conus medullaris, or cauda equina syndrome. Anatomically classifying the narrowest lesion in thoracolumbar spinal injuries is a useful method to clarify the differences and similarities between epiconus, conus medullaris, and cauda equina syndromes.

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References

1. Bradford DS and McBride GG: Surgical management of thoracolumbar spine fractures with incomplete neurologic deficits. Clin Orthop Relat Res (1987) 218: 201–216.
2. Gertzbein SD, Court-Brown CM, Marks P, Martin C, Fazl M, Schwartz M and Jacobs RR: The neurological outcome following surgery for spinal fractures. Spine (1988) 13: 641–644.
3. Kaneda K, Abumi K and Fujiya M: Burst fractures with neurologic deficits of the thoracolumbar-lumbar spine: results of anterior decompression and stabilization with anterior instrumentation. Spine (1984) 9: 788–795.
4. Korovessis P, Piperos G, Sidiropoulos P, Karagiannis A and Dimas T: Spinal canal restoration by posterior distraction or anterior decompression in thoracolumbar spinal fractures and its influence on neurological outcome. Eur Spine J (1994) 3: 318–324.
5. McAfee PC, Bohlman HH and Yuan HA: Anterior decompression of traumatic thoracolumbar fractures with incomplete neurological deficit using a retroperitoneal approach. J Bone Joint Surg Am (1985) 67: 89–104.
6. Transfeld EE, White D, Bradford DS and Roche B: Delayed anterior decompression in patients with spinal cord and cauda equina injuries of the thoracolumbar spine. Spine (1990) 15: 953–957.
7. Brouwers E, Meent Hvd, Curt A, Starremans B, Hosman A and Bartels R: Definitions of traumatic conus medullaris and cauda equina syndrome: a systematic literature review. Spinal Cord (2017) 55: 886–890.
8. Harrop JS, Naroji S, Maltenfort MG, Ratliff JK, Tjoumakaris SI, Frank B, Anderson DG, Albert T and Vaccaro AR: Neurologic improvement after thoracic, thoracolumbar, and lumbar spinal cord (conus medullaris) injuries. Spine (2011) 36: 21–25.
9. Kim NH, Lee HM and Chun IM: Neurologic injury and recovery in patients with burst fracture of the thoracolumbar spine. Spine (1999) 24: 290–294.

10. Demiryürek D, Aydingöz Ü, Akşit MD, Yener N and Geyik PO: MR imaging determination of the normal level of conus medullaris. Clin Imaging (2002) 26: 375–377.
11. Macdonald A, Chatrath P, Spector T and Ellis H: Level of termination of the spinal cord and the dural sac: a magnetic resonance study. Clin Anat (1999) 12: 149–152.
12. Saifuddin A, Burnett SJD and White J: The variation of position of the conus medullaris in an adult population: a magnetic resonance imaging study. Spine (1998) 23: 1452–1456.
13. Nakamae T, Fujimoto Y, Yamada K, Tanaka H, Shimbo T and Tsuchida Y: Percutaneous vertebroplasty for osteoporotic vertebral compression fracture with intravertebral cleft associated with delayed neurologic deficit. Eur Spine J (2013) 22: 1624–1632.
14. Toribatake Y, Baba H, Kawahara N, Mizuno K and Tomita K: The epiconus syndrome with radicular-type neurological features. Spinal Cord (1997) 35: 163–170.
15. Frankel HL, Hancock DO, Hyslop G, Melzak J, Michaelis LS, Ungar GH, Vernon JD and Walsh JJ: The value of postural reduction in the initial management of closed injuries of the spine with paraplegia and tetraplegia. I. Paraplegia (1969) 7: 179–192.
16. Thompson A: Fifth annual report of the committee of collective investigation of the anatomy society of Great Britain and Ireland for the year 1983-1894. J Anat Physiol (1894) 29: 46–48.
17. Needles JH: The caudal level of termination of the spinal cord in American whites and American negroes. Anat Rec (1935) 63: 417–425.
18. Denis F: The three column spine and its significance in the classification of acute thoracolumbar spinal injuries. Spine (1983) 8: 817–831.
19. Asada T, Koda M, Funayama T, Takahashi H, Noguchi H, Miura K, Mataki K and Yamazaki M: Imaging-based diagnosis of epiconus syndrome from the distance of the lesion to where the spinal cord terminates not from the disc level: a case series. Cureus (2021) 13: e17708.
20. Hashimoto T, Kaneda K and Abumi K: Relationship between traumatic spinal canal stenosis and neurological deficits in thoracolumbar burst fractures. Spine (1988) 13: 1268–1272.
21. Bullough PG and Boachie-Adjei O: Development of the spinal cord: in atlas of the spinal diseases. JB Lippincott, Philadelphia (1988) pp53.
22. Kameyama T, Hashizume Y and Sobue G: Morphologic features of the normal human cadaveric spinal cord. Spine (1996) 21: 1285–1290.
23. DiPietro MA: The conus medullaris: normal US findings throughout childhood. Radiology (1993) 188: 149–153.
24. Wall EJ, Cohen MS, Abitbol JJ and Garfin SR: Organization of intrathecal nerve roots at the level of the conus medullaris. J Bone Joint Surg (1990) 72-A: 1495–1499.
25. Podnar S: Epidemiology of cauda equine and conus medullaris lesions. Muscle Nerve (2007) 35: 529–531.
26. Clohisy JC, Akbarnia BA, Bucholz RD, Burkus JK and Backer RJ: Neurological recovery associated with anterior decompression spine fractures at the thoracolumbar junction (T12-L1). Spine (1992) 17(8 Suppl): s325–330.
27. Rahimi-Movaghar V, Vaccaro AR and Mohammadi M: Efficacy of surgical decompression in regard to motor recovery in the setting of conus medullaris injury. J Spinal Cord Med (2006) 29: 32–38.
28. Radcliff KE, Kepler CK and Delasotta LA: Current management review of thoracolumbar cord syndromes. Spine J (2011) 11: 884–892.