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Evaluation of Experimentally Induced Lumbar Spinal Cord Injury by Somatosensory Evoked Potentials (SEPs) in Dogs

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Abstract : Changes in somatosensory evoked potentials (SEPs) which accompanied by insertion of foreign body in spinal canal were evaluated with clinical signs and positive contrasted myelography in dogs. Foreign bodies occupied 20-50% of spinal canal. Foreign bodies occupying about 50% of spinal canal were inserted into the animals of group II and III for 1 week and 2 days, respectively. Foreign bodies occupying about 20% of spinal canal were inserted into the animals of group IV, V, and VI for 1 week, 2 days, and 8 weeks, respectively. In group I (control group), sham operation (lateral laminectomy) was performed. Group III, IV and V did not severely affect on SEPs latencies and clinical signs. Group VI affects on SEPs latencies but not on clinical signs. After foreign body removal, SEPs latencies showed similar recovery patterns with clinical signs. However, group II induced severe abnormalities in SEPs latencies and clinical signs. In group III, IV and V, thoracic potentials (TN1) were abnormally recorded after foreign body insertion and firstly/normally recorded on the 6th, 9.5th and 3.5th day after foreign body (removal following) insertion. In group VI, TN1 was abnormally recorded after foreign body insertion and firstly recorded on the 7.7th day and normally recorded on 34th day after foreign body insertion. In group I, TN1 was not recorded from the 3rd day after foreign body insertion and until the 8th week after foreign body removal. In group I, TN1 was firstly recorded on the 1st day after laminectomy. In group III, IV and V, the normalized interwave latencies of 'LP1-TN1' were recorded on the 6th, 11th and 4.5th day after foreign body (removal following) insertion. In group VI, the normalized interwave latency of 'LP1-TN1' was recorded on the 35.7th day after foreign body insertion. In group II, the normalized interwave latency of 'LP1-TN1' did not recovered until 8 week after foreign body removal. In group I, the normal interwave latency between 'LP1-TN1' was recorded on the 1st day after laminectomy. Delayed SEP latencies without clinical signs could mean the spinal cord dysfunction caused by spinal cord compression. Therefore, SEPs would be useful to evaluate the functional spinal cord dysfunction.

Key words **:** dog, somatosensory evoked potentials, spinal cord injury, spinal cord dysfunction

Introduction

Spinal cord disorders can be classified into the degenerative, anomalous, metabolic, neoplastic, inflammatory, granulomatous, immune-mediated, toxic, traumatic and vascular causes[3,8].

Trauma is probably the main cause of spinal cord disorders in dogs and cats[3,16]. Trauma can arise from external sources such as car accidents and internal sources including disc herniation, disc protrusion, and pathologically collapsed vertebrae.

The neurologic assessment of animal patients with hindlimb problems helps to confirm that the disease is neurologic in nature and where pathologic lesion is located. After the lesion localization, specialized tests may be indicated, based on physical examination findings. Tests for infectious diseases, electro- diagnostic tests and imaging techniques are the kinds of specialized tests[3].

Myelography is the most commonly performed special neuro-radiographic procedure and is helpful in differentiating intramedullary or extramedullary spinal cord lesions. But, this method is inhibited in the presence of CNS inflammation and impossible to know the severity of spinal cord injury, whereas computerized tomography (CT) and magnetic resonance imaging (MRI) can provide more detailed information.

Electro-diagnostic tests (such as electromyography, nerve conduction velocity, motor evoked potentials and sensory evoked potentials) are useful in evaluation of the spinal cord diseases[1,10,17].

Especially, SEPs can evaluate the integrity of the ascending spinal cord tracts to determine the extent of functional damages[9,15,16].

The diagnosis of spinal cord disorders by SEPs has not been studied in toy breed dogs. In this experiment, Hansen's type I IVD was induced by inserting bone fragments into spinal canal, and SEPs were analysed with clinical signs and radiological findings to confirm the usefulness in evaluating the spinal cord injury and presuming its severity.

Materials and Methods

Experimental animals

Clinically healthy twenty-four dogs (3.0-4.3 kg and 2-5 years) were divided into six groups regardless of their sexes. In group I (sham-treated group), no compression was performed after the lateral laminectomy. Large foreign bodies occupying about 50% of spinal canal were inserted into the animals of group II and III for 1 week and 2 days, respec-

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tively. Small foreign bodies occupying about 20% of spinal canal were inserted into the animals of group IV, V, and VI for 1 week, 2 days, and 8 weeks, respectively.

Anesthesia

Thiopental sodium (15 mg/kg, Penthotal sodium®, Joongwei, Korea) was intravenously injected to induce the anesthesia after premedication of acepromazine maleate (0.01 mg/kg, Sedaject®, Samwoo, Korea) and isoflurane (Aerane®, Ilsung, Korea) was used to maintain anesthesia.

Spinal cord compression

The skin region from 3rd to 4th lumbar vertebrae was incised and hemilaminectomy was performed to make the window of 10×5 mm on the lamina. In group II and III, 10 ×5×3 mm size bone fragment was inserted through the window, and 5×3×2 mm size bone fragment was inserted in group IV, V and VI.

SEPs measurement

In group I, SEPs were recorded on the 1st, 3rd day and 1st, 2nd, 3rd, 4th, 5th, 6th, 7th and 8th week after the hemilaminectomy. The SEPs of group II and IV were recorded on the 1st, 3rd day after foreign body insertion and on the 1st, 3rd day and 1st, 2nd, 3rd, 4th, 5th, 6th, 7th, 8th week after the foreign body removal. The SEPs of group III and V were recorded on the 1st day after foreign body insertion and on the 1st, 3rd day and 1st, 2nd, 3rd, 4th, 5th, 6th, 7th, 8th week after it's removal. In group VI, SEPs were recorded on the 1st, 3rd day and 1st, 2nd, 3rd, 4th, 5th, 6th, 7th and 8th week after foreign body insertion.

The SEPs were recorded on two channels by stimulating the posterior tibial nerve of the left hindlimb. The lumbar recording electrode (channel 1) was located on the subdermal region between the 5th and 6th lumbar vertebrae and the thoracic recording electrode (channel 2) was positioned between the 11th and 12th thoracic vertebrae.

The distance from the electro-stimulating point on the posterior tibial nerve to lumbar recording electrode and the distance from the lumbar recording electrode to thoracic recording electrode were measured. The latencies of P1 and N1 were recorded.

Apparatus for experiments

'MEM-7102' (Nihon Kohden, Japan) model was used to measure the SEPs and the subdermal 'platinum needle electrode' (Grass, USA) was applied on the two channels.

Condition of the SEPs stimulation

The posterior tibial nerves were stimulated with needle electrodes. The nature of the stimulation was electro-stimulation. Stimulation was conducted with 0.2 msec, 2 Hz and 4 mA. The supramaximal stimulation intensity was used at least three times of the response threshold. SEPs were averaged over 100 times in each recording.

Clinical signs

The day when experimental animals stand to walk, proprioception and deep pain responses were examined.

Radiological study

The spinal cord injury was observed anatomically through the myelograms.

Results

Somatosensory evoked potentials (SEPs) after foreign body insertion into spinal cord and foreign body removal were measured.

In group I, LP1, LN1, TP1 and TN1 peak waves were noted just before laminectomy and the 1st day, 1st, 4th and 8th week after laminectomy (Fig 1-Fig 5). The latencies of TP1 and TN1 were not delayed on each recording after laminectomy.

In group II, clear LP1, LN1, TP1, and TN1 peak waves

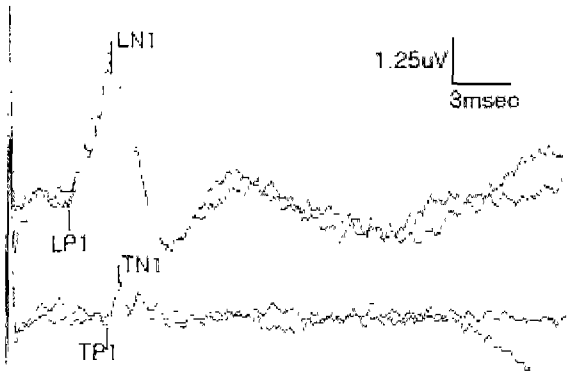

Fig 1. Somatosensory evoked potentials (SEPs) before laminectomy in sham operated group.

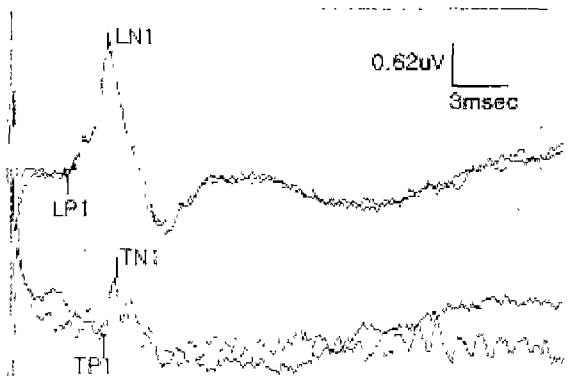

Fig 2. SEPs on the 1st day after laminectomy in sham operated group.

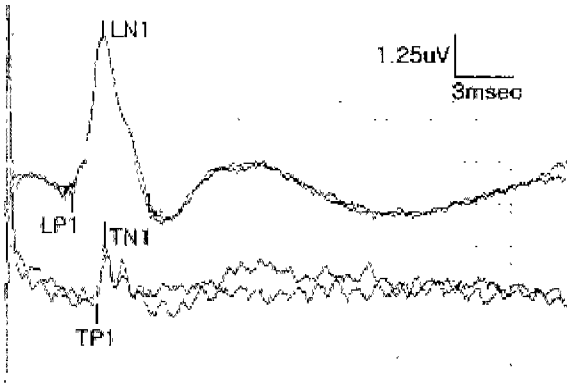

Fig 3. SEPs on the 1st week after laminectomy in sham operated group.

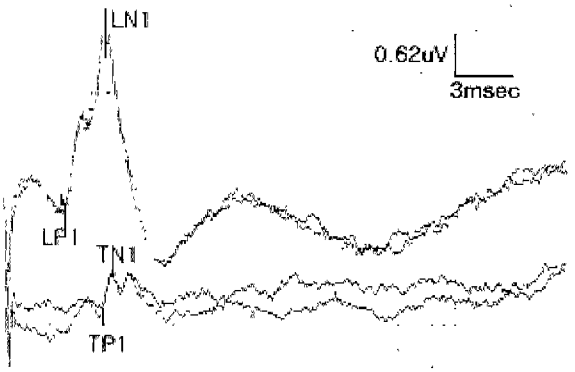

Fig 4. SEPs on the 4th week after laminectomy in sham operated group.

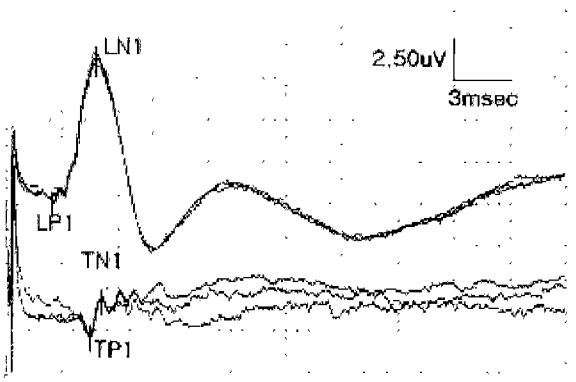

Fig 5. SEPs on the 8th week after laminectomy in sham operated group.

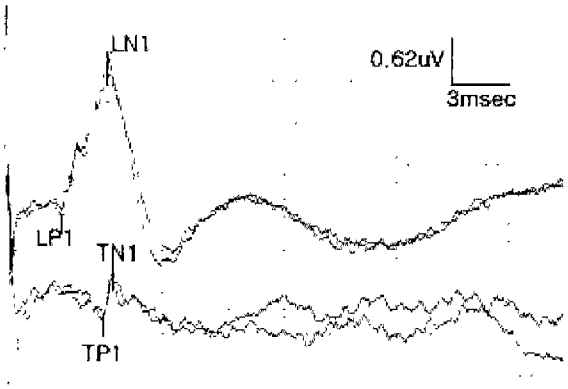

Fig 6. SEPs before insertion of foreign body which occupies 50% of spinal canal.

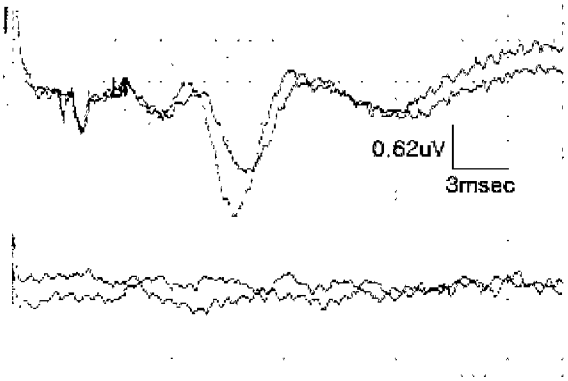

Fig 7. SEPs on the 3rd day after insertion of foreign body which occupies 50% of spinal canal.

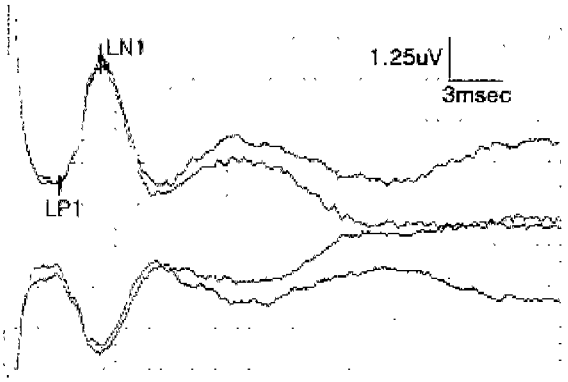

Fig 8. SEPs on the 1st day after removal of foreign body which occupies 50% of spinal canal.

were noted before insertion of foreign body which occupies 50% of spinal canal (Fig 6). However, TP1 and TN1 peak waves were not recorded on the 3rd day after foreign body insertion and on the 1st day, 1st and 8th week after the removal of foreign body, while LP1 and LN1 waves were clear on the 1st day, 1st and 8th week after foreign body removal (Fig 8-Fig 10).

In group IV, clear LP1, LN1, TP1, and TN1 peak waves were noted before insertion of foreign body which occupies 20% of spinal canal (Fig 11).

TP1 and TN1 peak waves were obvious on the 3rd day after insertion of the foreign body as well as on the 1st and

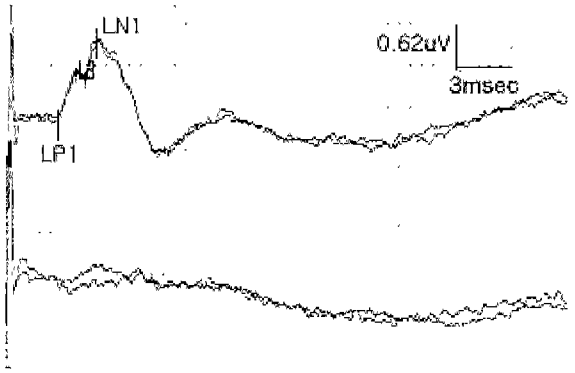

Fig 9. SEPs on the 1st week after removal of foreign body which occupies 50% of spinal canal.

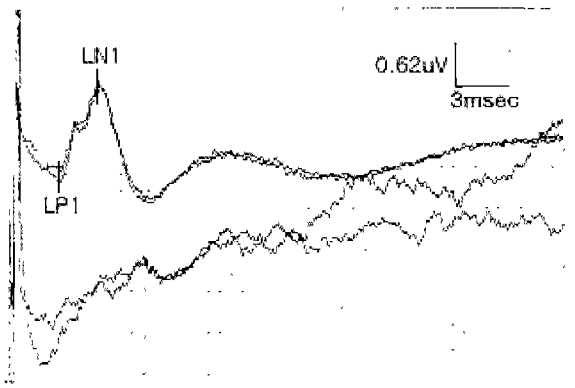

Fig 10. SEPs on the 8th week after removal of foreign body which occupies 50% of spinal canal.

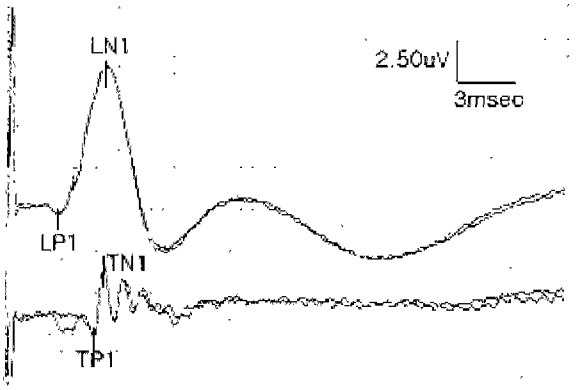

Fig 11. SEPs before insertion of foreign body which occupies 20% of spinal canal.

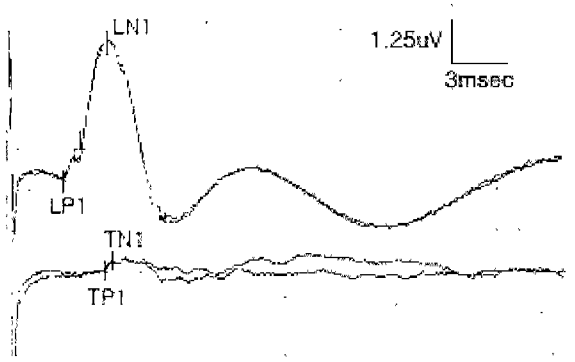

Fig 12. SEPs on the 3rd day after insertion of foreign body which occupies 20% of spinal canal.

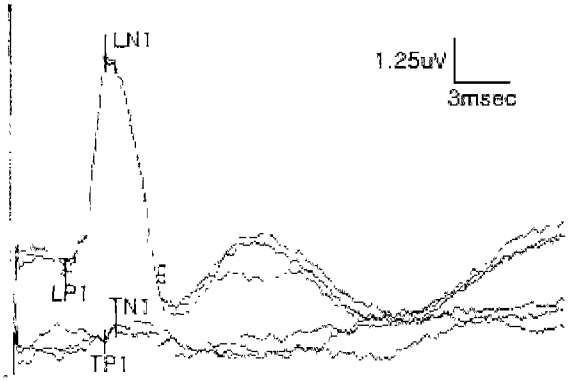

Fig 13. SEPs on the 1st week after removal of foreign body which occupies 20% of spinal canal.

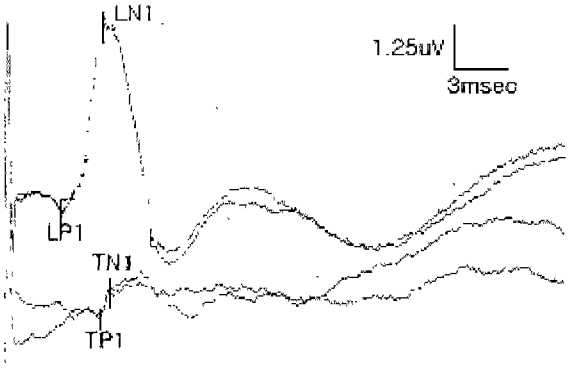

Fig 14. SEPs on the 4th week after removal of foreign body which occupies 20% of spinal canal.

4th week after foreign body removal. LP1 and LN1 peak waves were obvious on the 1st and 4th week after foreign body removal (Fig 13-Fig 14).

Group III, IV and V showed similar wave patterns on each recording.

In group VI, clear LP1, LN1, TP1, and TN1 peak waves were noted before insertion of foreign body and on the 1st and 8th week after foreign body insertion which occupies 20% of spinal canal (Fig 15-Fig 17).

The latencies of TP1 and TN1 were slightly delayed on the 1st week after foreign body insertion, but those were normally recorded on the 8th week after foreign body inser-

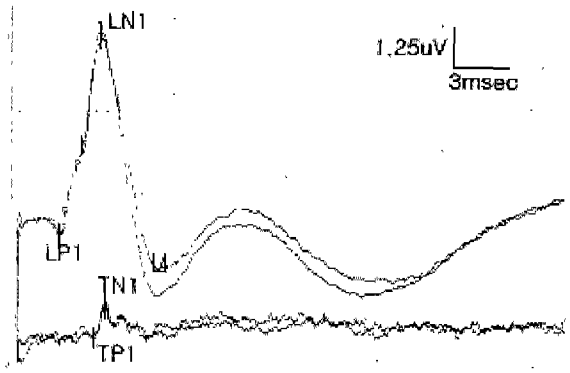

Fig 15. SEPs before insertion of foreign body which occupies 20% of spinal canal.

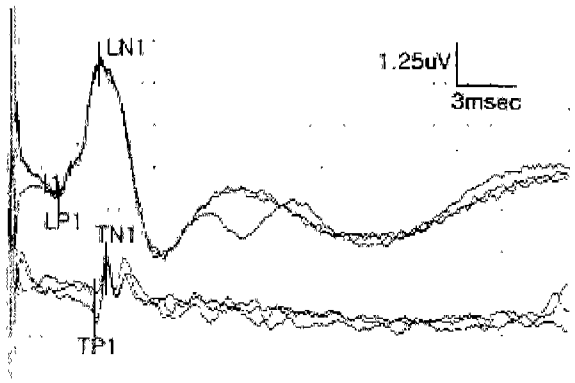

Fig 16. SEPs on the 1st week after insertion of foreign body which occupies 20% of spinal canal.

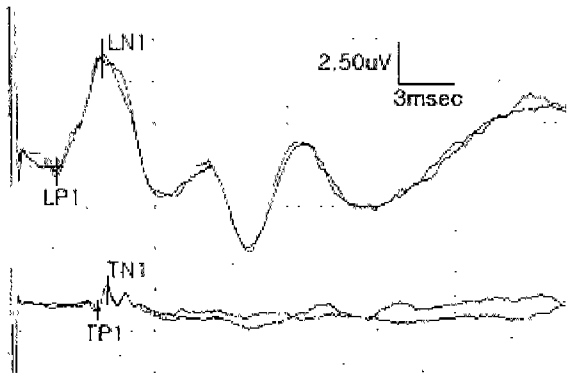

Fig 17. SEPs on the 8th week after insertion of foreign body which occupies 20% of spinal canal.

tion (Fig 16-Fig 17).

SEP measurement

In group I, TN1 was firstly recorded on the 1st day after laminectomy and the normal range of TN1 latency and velocity were also recorded on the 1st day after laminectomy.

In group II, TN1 was not recorded until the 8th week after foreign body removal following insertion and the normal range of TN1 latency and velocity were also not observed until the 8th week after foreign body removal following insertion (Table 1).

In group III, IV and V, first recordings of TN1 were on the 6th, 9.5th and 3.5th day after foreign body removal following insertion, respectively (Table 1), and the normal range of TN1 latency and velocity were also recorded on the 6th, 9.5th and 3.5th day after foreign body removal following insertion (Table 1).

In group VI, first recording of TN1 was on the 7.7th day after foreign body insertion (Table 1), while the normal range of TN1 latency and velocity were recorded on the 34th day after foreign body insertion (Table 1).

In group I, the normal range of 'LP1-TN1' latency and velocity were recorded on the 1st day after laminectomy.

In group II, normal range of 'LP1-TN1' latency and velocity were not recovered until the 8th week after foreign body removal (Table 2).

In group III, IV and V, the normal recovery of 'LP1-TN1' latency and velocity were recorded on the 6th, 11st and 4.5th day after foreign body removal following insertion (Table 2).

In group VI, the normal recovery of 'LP1-TN1' latency and velocity were recorded on the 35.7th day after foreign body insertion (Table 2).

Table 1. The days firstly recorded and normally recovered in TN1 waves

	Group				
	II	III	IV	V	VI
Duration of FBI[a]	7*	2	7	2	56
Firstly recorded day after					
FBI	-	-	-	-	7.7
FBR[b]	-	4	2.5	1.5	-
FBRI[c]	-	6	9.5	3.5	7.7
Normally recovered day after					
FBI	-	-	-	-	34
FBR	-	4	2.5	1.5	-
FBRI	-	6	9.5	3.5	34

Four heads in each group were used. In group I, foreign body was not inserted, and the normal range latency of TN1 was recorded on the 1st day after laminectomy. In group II, the SEPs were not observed until the 8th week. *days, [a]means foreign body insertion, [b]means foreign body removal, [c]means foreign body removal following insertion

Clinical signs

In group I, proprioception, deep pain and walking were observed on the 1st day after laminectomy

Table 2. The day recovered to the normal latency in LP1-TN1 interwaves

	Group				
	II	III	IV	V	VI
Duration of FBI[a]	7*	2	7	2	56
Normally recorded day after					
FBI	-	-	-	-	35.7
FBR[b]	-	4	4	2.5	-
FBRI[c]	-	6	11	4.5	35.7

Four heads in each group were used. In group I, foreign body was not inserted, and the normal range latency of LP1-TN1 was recorded on the 1st day after laminectomy. In group II, the SEPs were not observed until the 8th week. *days, [a]means foreign body insertion, [b]means foreign body removal, [c]means foreign body removal following insertion

Table 3. The day when clinical signs were firstly recorded

	Group				
	II	III	IV	V	VI
Duration of FBI	7*	2	7	2	56
Proprioception after					
FBI[a]	-	-	-	-	10.7
FBR[b]	-	6.5	1.5	2.5	-
FBRI[c]	-	8.5	8.5	4.5	10.7
Deep pain after					
FBI	-	-	-	-	2
FBR	3	1.5	1	1	-
FBRI	10	3.5	8	3	2
Walking after					
FBI	-	-	-	-	12.5
FBR	-	7.5	1	2.5	-
FBRI	-	9.5	8	4.5	12.5

Four heads in each group were used. In group I, foreign body was not inserted. In group II, the proprioception and walking were not observed until the 8th week. *days, [a]means foreign body insertion, [b]means foreign body removal, [c]means foreign body removal following insertion

In group II, the proprioception and walking were not shown until the 8th week after the foreign body removal, whereas, the deep pain response began to recover on the 10th day after foreign body removal following insertion (Table 3).

In group III, IV and V, proprioception was observed on the 8.5th, 8.5th and 4.5th day after foreign body removal following insertion, deep pain was felt on the 3.5th, 8th and 3rd day after foreign body removal following insertion, and walking was shown on the 9.5th, 8th and 4.5th day after foreign body removal following insertion, respectively.

In group VI, proprioception, deep pain and walking were observed on the 10.7th, 2nd and 12.5th day after foreign body insertion, respectively.

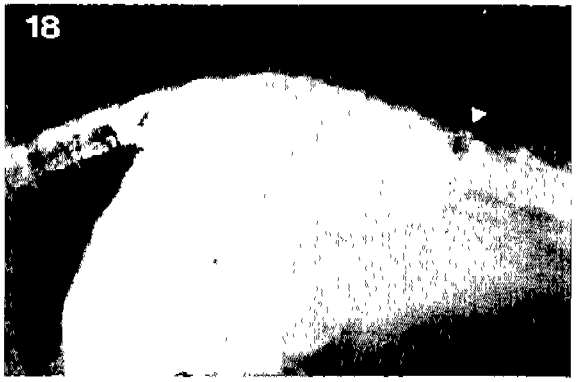

Fig 18. Myelograph of lumbar vertebrae on the 1st day after insertion of foreign body which occupies 50% of spinal canal in group II.

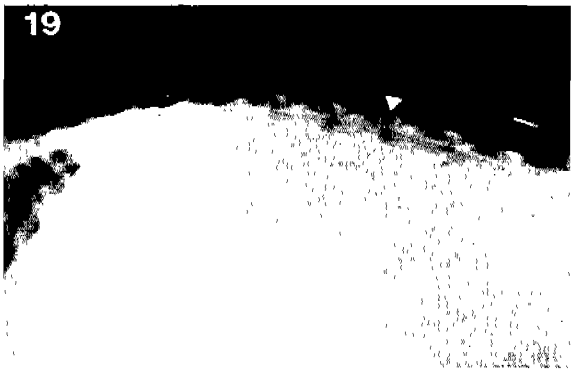

Fig 19. Myelograph of lumbar vertebrae on the 1st day after insertion of foreign body which occupies 20% of spinal canal in group IV.

Radiological studies

Myelogram was performed on the 1st day after foreign body insertion in group II and IV (Fig 18-19). There were no significant myelographic differences in these groups.

Discussion

It has been established experimentally that not only mechanical deformation but the mere presence of autologous nucleus pulposus material in the epidural space may induce significant morphologic and functional injury of the adjacent nerve roots[11].

The annulus fibrosus ruptures allow the extrusion of the degenerative nucleus into the neural canal, and compress the spinal cord. Not only the IVD (intervertebral disk) material compresses the spinal cord, but the degenerative material is irritative in nature on spinal cord. Therefore, the presence of the herniated material in the epidural space causes inflammation.

The bone fragments which occupies 50% or 20% of spi-

nal canal were used to induce experimental IVD in this experiment, although the physical or chemical effects of bone fragments on spinal cord might be different from naturally occurred vertebral disk.

In most cases, lumbosacral lesions do not effect on forelimb responses, but show LMN signs on hindlimb and perineal responses[2,14].

In group II, LMN signs were induced on hindlimb after foreign body removal following insertion, but not on forelimb. In group III, IV, V and VI, there were no neurologic signs after spinal cord injury.

The loss of SEPs and neurologic, histological abnormalities occurred at 50% compression of the cauda equina, but 25% constriction was not revealed abnormal SEP and neurologic signs[5]. The cauda equina that compressed 50% of spinal canal was in the critical point of possible recovery[5].

In this experiment, the groups inserted large foreign body (which occupies 50% of spinal canal) for 1 week showed abnormal SEPs latency and velocity. However, it was revealed that the group inserted the large foreign body for 2 days, and the group inserted the small foreign body for 1 week or 2 days had normal SEPs.

SEPs revealed abnormalities before neurologic signs appeared. If delayed SEPs were recovered with the lapse of time, neurologic findings showed gradual recovery[5,6].

In group VI, TN1 was firstly shown on the 7.7th day after foreign body insertion, and the proprioception and walking were revealed on the 10.7th and 12.5th day after foreign body insertion. However, the normal range latency of TN1 was shown on the 34th day after foreign body insertion. The day of normal range latency of TN1 was more delayed than that of TN1 which was firstly recorded. That may be due to the foreign body that remained in spinal canal.

In group IV, TN1 was firstly revealed on the 9.5th day, and the proprioception and walking were shown on the 8.5th and 8th day after foreign body removal following insertion.

In first stage of disk compression, SEPs might be useful to distinguish the group VI from group IV. However, it could not be differentiated between group VI and IV by SEPs in 5th week after foreign body insertion in this experiment.

In group III, IV and V, proprioception and walking showed similar recovery pattern with normal TN1 and normal 'LP1-TN1' latency.

In group II, TN1 latency, 'LP1-TN1' interwave latency, proprioception and walking were not observed until the 8th week after foreign body removal. However, the deep pain response was recorded on the 10th day after foreign body removal following insertion, suggesting that spinal cord was not completely dysfunctional.

Many patients will benefit from corticosteroid management during the initiation of treatment[3,4]. Non-surgical management of IVD disease should include cage rest for a minimum of 30 days. In this experiment, the animal was confined in each cage and corticosteroid was not administered in all groups.

The diagnosis of IVD disease is made with SEP, radiographs and myelography. In some cases, CSF analysis helps to rule out meningomyelitis. In this experiment, there was no difference in the myelographic change according to the size of foreign body.

Shore *et al*[13] recorded SEPs from electrodes placed percutaneously at the lumbosacral junction and between the 10th and 11th thoracic vertebra following tibial nerve stimulation in 31 acute compressive spinal cord injuries. In this experiment, the operation was performed between the 3rd and 4th lumbar vertebra to injure the spinal cord and two channels were arranged distal and proximal region of injury. The channel 1 was recorded between the 5th and 6th lumbar vertebra and channel 2, between the 11th and 12th thoracic vertebra.

The favorable velocities of L7-S1 and T10-11 SEPs were 86.01 ± 6.96 m/sec and 56.12 ± 10.97 m/sec[13]. In this experiment, the normal lower limits of velocities of L5-6 (LP1) and T11-12 (TN1) were 71.66 m/sec and 59.33 m/sec.

EPs and MRI are largely complementary tests. The former provides a 'view' of functional anatomy, whereas the latter mainly registers structure. Clinical studies have been reported about some cases which one test has missed a lesion detected by the other. For example, MRI might miss small lesion in the brain stem revealed by abnormal short-latency EPs[7].

Magnetic resonance imaging has been shown to be better than EPs and CT in revealing multiple lesions in the CNS, including the spinal cord, but MRI is no more specific than EPs with respect to etiology[7]. In this experiment, SEPs were investigated with myelogram to gain more information about the severity and lesions of spinal cord injury.

The latencies of the individual components and the intervals between different components such as height or limb length were examined to assess the SEPs responses[17], therefore, the latency and hindlimb length were recorded together in this experiment.

EP tests provide sensitive, quantitative extensions of the clinical neurologic examination. Sometimes the absence of a wave or an abnormal configuration on its potential field also provides useful information[1].

In evaluation of prognosis by cortical somatosensory evoked potentials (CSEP), safe limits of prolonged P1 wave latency should be less than 1.5 times, and those of declining P1-N1 wave amplitude should be less than 50 percent. These results indicated that CSEP monitoring of spinal cord injury could also predict an accurate prognosis for the injured spinal cord in this canine model[12].

In this experiment, SEPs latency, clinical sign and radiography were examined to identify the relationship between the spinal cord dysfunction and size of foreign body inser-

tion (and inserted duration). Small foreign body which occupies 20% of spinal canal would not severely affect on spinal cord function regardless of duration of insertion, although the recovery rate of normal range latencies of TN1 and 'LP1-TN1' were delayed compared with that of proprioception and walking. Large foreign body which occupies 50% of spinal canal could occur severe spinal cord dysfunction, if it was not removed within 2 days. SEPs, therefore, would be helpful in diagnosis of the spinal cord dysfunction in dogs.

Conclusion

The days that normal range of SEPs and clinical signs were firstly recorded were examined.

In group III, IV and V, thoracic potentials (TN1) were abnormally recorded just after foreign body insertion and the first normal TN1 were recorded on the 6th, 9.5th and 3.5th day after foreign body removal following insertion. In group VI, TN1 was abnormally recorded after foreign body insertion and firstly recorded from the 7.7th day and normally recorded on 34th day after foreign body insertion. In group II, TN1 was not recorded from the 3rd day after foreign body insertion until the 8th week after foreign body removal. In group I, TN1 was firstly recorded on the 1st day after laminectomy.

In group III, IV and V, the normalized interwave latencies of 'LP1-TN1' were recorded on the 6th, 11th and 4.5th day after foreign body (removal following) insertion. In group VI, the normalized interwave latency of 'LP1-TN1' was recorded on the 35.7th day after foreign body insertion. In group II, the normalized interwave latency of 'LP1-TN1' was not recovered until the 8th week after foreign body removal. In group I, the normal interwave latency between 'LP1-TN1' was recorded on the 1st day after laminectomy.

In group III, IV and V, proprioception was observed from the 4.5th to 8.5th day after foreign body removal following insertion, and deep pain from the 3rd to 8th day, and walking from the 4.5th to 9.5th. In group VI, proprioception, deep pain response and walking were observed on the 10.7th, 2nd and 12.5th day after the foreign body insertion. In group II, proprioception and walking were not found until the 8th week after the foreign body removal. The deep pain response in group II was started to recover on the 3rd day after foreign body removal.

Delayed SEP latencies without clinical signs could mean the spinal cord dysfunction caused by spinal cord compression. Therefore, SEPs would be useful to evaluate the functional spinal cord dysfunction.

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개에서 Somatosensory Evoked Potentials (SEPs)을 이용한 척수기능장애의 평가

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초 록 : 본 실험에서는 인공적으로 척수관의 20-50%를 차지하는 이물을 척수관내에 삽입한 후 이물제거 시기에 따라 somatosensory evoked potentials (SEPs) 변화상을 임상증상과 척수조영술을 이용하여 비교 관찰하였다. 실험군은 척수관의 50%를 차지하는 이물을 삽입하여 1주일 후에 제거한 군(II군), 2일 후에 제거한 군(III군). 또 척수관의 20%를 차지하는 이물을 삽입하여 1주일 후에 제거한 군(IV군), 2일 후에 제거한 군(V군), 8주 계속 유지한 군(VI군) 그리고 대조군으로 laminectomy만을 실시한 군(I군)으로 나누었다. 척수관 직경의 50%를 차지하는 큰 이물을 삽입하여 2일간 유지하였다가 제거한 후 관찰한 군(III군), 척수관 직경의 20%를 차지하는 작은 이물을 삽입하여 1주일간 유지하였다가 제거한 후 관찰한 군(IV군), 작은 이물을 삽입하여 2일간 유지하였다가 제거한 후 관찰한 군(V군)에서는 SEPs latency와 임상증상에서 거의 이상이 나타나지 않았다. 작은 이물을 8주간 계속 유지한 군(VI군)에서는 SEPs latency에서는 약간의 이상을 보였으나 임상증상에서 거의 이상이 나타나지 않았다. 척수압박 후 제거한 각각의 군에서 SEPs latency와 임상증상은 비슷한 회복추이를 보였다. 그러나 척수관 직경의 50%를 차지하는 큰 이물을 삽입하여 1주일간 유지하였다가 제거한 후 관찰한 군(II군)에서는 TN1의 SEPs latency는 기록되지 않았으며, 임상적으로 신경증상을 나타내었다. III, IV 및 V 군에서 TP1과 TN1(T11과 T12사이)은 이물 삽입 직후에는 비정상적으로 기록되었고 처음으로 TP1과 TN1 값이 기록된 날은 이물을 삽입하였다가 제거한 후 각각 6일, 9.5일 및 3.5일째였다. VI군에서 TN1의 유발전위는 이물삽입 후 7.7일째부터 기록되었고 34일째에 정상적인 파형을 보였다. II군에서 TN1의 유발전위는 이물을 삽입하였다가 제거한 후 8주째 까지 기록되지 않았다. I군에서 TN1 값은 laminectomy 후 1일째에 처음으로 기록되었다. III, IV 및 V군에서 'LP1-TN1'의 정상적인 파간 잠복기가 기록되기 시작하는 날은 이물을 삽입하였다가 제거한 후 각각 6일, 11일 및 4.5일째이다. VI군에서는 정상적인 파간 잠복기는 이물삽입 후 35.7일째부터 기록되었다. II군에서 'LP1-TN1'의 정상적인 파간 잠복기는 이물을 삽입하였다가 제거한 후 8주째 까지 회복되지 않았다. I군에서 'LP1-TN1' 사이의 정상적인 파간 잠복기가 나타나기 시작하는 시기는 laminectomy후 1일째부터이다. 신경증상은 없으나 SEPs가 지연되는 경우에는 척수 압박을 동반한 척수의 기능장애 가능성이 있을 수 있다. 따라서 SEPs는 척수기능장애를 평가하는데 유용하게 사용될 수 있다고 생각된다.