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SHORT COMMUNICATION

PREVALENCE OF SPASTICITY AND BELOW-LEVEL NEUROPATHIC PAIN RELATED TO SPINAL CORD INJURY LEVEL AND DAMAGE TO THE LOWER SPINAL SEGMENTS

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Objective: To evaluate spasticity and below-level spinal cord injury neuropathic pain after spinal cord injury in patients with, or without, damage to the lumbar spinal cord and roots.
Design/patients: Chart review of 269 patients with spinal cord injury from segments C1 to T11.
Methods: Patients were interviewed concerning leg spasticity and below-level spinal cord injury neuropathic pain in the lower trunk and legs. Damage to the lumbar spinal cord and roots was inferred where there was radiological evidence of a vertebral fracture, spinal stenosis or the narrowing of spinal foramina of a vertebra from thoracic 11 to lumbar 5, or; magnetic resonance imaging showing evidence of damage to the lumbar spinal cord and roots.
Results: Among 161 patients without damage to the lumbar spinal cord and roots, 87% of those with cervical spinal cord injury experienced spasticity, compared with 85% with thoracic spinal cord injury. The corresponding figures for patients in whom damage to the lumbar spinal cord and roots was present were 57% and 52%, respectively. Below-level spinal cord injury neuropathic pain was not associated with damage to the lumbar spinal cord and roots. In those patients with no damage to the lumbar spinal cord and roots, regression showed that neither outcome was significantly associated with the level of spinal cord injury.
Conclusion: The lack of segmental dependency for spinal cord injury and spasticity suggests mechanisms restricted mainly to the lumbar spinal cord. For below-level spinal cord injury neuropathic pain, additional mechanisms, other than lesions of the spino-thalamic tract, must be considered.

Key words: spinal cord injury; spasticity; neuropathic pain; lumbar spine stenosis.

LAY ABSTRACT

Following a spinal cord injury, symptoms of increased nerve cell activity in the central nervous system appear, e.g. involuntary muscle activity (spasticity), below level neuropathic pain and urinary leakage. The distribution of overactive neurons is still unresolved. This chart review showed that leg spasticity was more frequent in patients with a cervical or thoracic spinal cord injury if the patients had no signs of damage to the lumbar spinal cord and roots. The occurrence of leg spasticity and below level spinal cord injury neuropathic pain was unrelated to each other or to the level of the spinal cord injury. This suggests that the mechanisms behind leg spasticity are mainly restricted to the lumbar spinal cord. For this pain, additional mechanisms other than lesions of the spino-thalamic tract must be considered

Within weeks of spinal cord injury (SCI), symptoms of increased nerve cell activity in the central nervous system appear, e.g. involuntary muscle activity (spasticity), below-level spinal cord injury neuropathic (BLSCIN) pain and urinary leakage. The distribution of overactive neurones is unknown. For spasticity, some evidence from animal experiments by Bellardita et al. (1) indicates the involvement of spinal interneurones. Jankowska & Hammar (2) proposed that interneurones in the lumbar segments may contribute to spasticity. It is possible that interneurones located even higher up might contribute to leg spasticity. In this case, the prevalence of

spasticity should be greater, as more disconnected spinal cord neurones contribute to the spasticity. BLSCIN pain, on the other hand, is thought to require a lesion of the spinothalamic tract. In this case, the resulting pain should be more prevalent where there is a large lesion of the tract, as in cervical SCI.

The primary objective of this study was, therefore, to investigate whether the prevalence of spasticity and BLSCIN pain is affected by SCI segmental level. Previous studies found a lower prevalence of spasticity where SCI level was lower, see Maynard et al. (3) and Skold et al. (4). In these studies, however, SCIs at the lumbar level were included. It is also possible that spasticity may not reflect the true overactivity of the neurones in the motor pathways. Can concomitant damage at lower spinal cord levels, e.g. the motor neurones and their axons, obscure the true prevalence? Lee & Lee (5) and Secil et al. (6) found motor neurone damage in persons with degeneration of the lumbar spine. To answer the primary objective, first it was necessary to determine whether the prevalence of spasticity in the legs of patients with an SCI at the cervical or thoracic level was affected by damage to the lumbar spinal cord and nerve roots (LSCR).

The question arises, as to whether spasticity and BLSCIN pain are dependent on specific lesions, e.g. of specific descending pathways, or whether there is an inclination to develop overactivity regardless of the neurones involved? In the first case, a large variation should occur in the relationship between spasticity and BLSCIN pain. In the latter case, more uniform changes should be prevalent. Previous studies have mapped the frequency of either spasticity or BLSCIN pain, but not the concurrence of these manifestations. The second objective was therefore to compare the pattern of overactivity of spasticity and BLSCIN pain among the patients.

METHODS

Approximately 400 individuals with an SCI attend the Department of Rehabilitation Medicine in Gothenburg. Questions regarding spasticity and BLSCIN pain are routinely posed to patients, and suitable study participants were enrolled in this study from amongst them. Patients with an SCI at thoracic level 12 or injury to the lumbar or sacral segments were excluded to avoid instances of SCI in which lesions of the lumbar or sacral motor neurones were present. With SCI at these levels it is also difficult to differentiate BLSCIN pain from peripheral nerve pain.

Study participants have either; a radiological investigation of the spine covering thoracic vertebra 11 and all lumbar vertebra in order to find changes suggesting the possibility of damage to LSCR or a magnetic resonance imaging (MRI) with more direct evidence for damage to LSCR.

Participants included 269 patients with an SCI located between segments C1 and T11 (**Table I**). The time elapsed between injury and interview ranged from 1 to 64 years, with a mean of 15 years. SCI severity was determined according to the American Spinal Cord Injury Association Impairment Scale (AIS). The cause of the cervical or thoracic SCI was traumatic in 194 patients, tumour in 19, vascular condition in 24, infection in 6, orthopaedic condition in 18 and diverse conditions in 3 patients. Twenty-three patients with incomplete SCI also had probable brain damage, e.g. traumatic injury or stroke.

Of the participants, 106 were investigated by MRI, 149 by computed tomography (CT) scan and 14 by ordinary X-ray. Damage to LSCR was evidenced by degenerative or traumatic changes to a vertebra from T11 to L5. The changes looked for included vertebral fracture, spinal stenosis, narrowing of spinal foramina or extensive osteophytes in the foramina (**Fig. 1**). Stenosis was defined as more than one-third reduction in the spinal canal area. Narrow spinal foramina were defined rather arbitrarily as having an anterior-posterior width of less than 4 mm on axial CT scans (7, 8). Of the patients examined with MRI, 13 had direct damage to the lumbar spinal cord (apart from the SCI higher up); 8 had syringo-myelia, there was 1 distal effect of a thoracic gunshot wound, 1 distal effect of an electric burn, 1 previous spinal infarction, 1 previous bleeding and 1 myelitis of the lumbar segments. Vertebral changes and direct evidence from MRI were both considered as damage to LSCR.

Table I. Characteristics of the patients with spinal cord injury

	Total				No damage to LSCR				Damage to LSCR			
	n	Spasticity %	Troublesome spasticity %	BLSCIN pain %	*n*	Spasticity %	Troublesome spasticity %	BLSCIN pain %	*n*	Spasticity %	Troublesome spasticity %	BLSCIN pain %
Total	269	74	45	28	161	86	53	30	108	55	34	25
Cervical SCI	155	77	51	28	101	87	54	30	54	57	44	24
Thoracic SCI	114	69	38	29	60	85	50	32	54	52	24	26
AIS A	84	80	44	32	59	86	49	24	25	64	32	52
AIS B	28	96	68	32	26	100	69	35	2	50	50	0
AIS C	39	82	59	33	22	95	73	45	17	65	41	18
AIS D	118	61	36	23	54	76	41	30	64	48	33	17
Traumatic SCI	196	80	49	31	132	89	54	29	64	63	41	36
Non-traumatic SCI	73	56	34	21	29	76	48	38	44	43	25	9
Female	65	66	38	26	38	79	50	29	27	48	22	22
Male	204	76	48	29	123	89	54	31	81	57	38	26
Current age, years	53 (range 15–87)				49 (15–85)				60 (19–87)			
Years since SCI	15 (range 1–64)				17 (1–64)				12 (1–51)			
MRI	106				53				53			
CT	149				98				51			
X-ray	14				10				4			

Characteristics of patients with or without suspected damage to lumbar spinal cord and roots. SCI: spinal cord injury; BLSCIN: below-level spinal cord injury neuropathic; AIS: American Spinal Cord Injury Association Impairment Scale; LSCR: lumbar spinal cord and roots; MRI: magnetic resonance imaging; CT: computerized tomography.
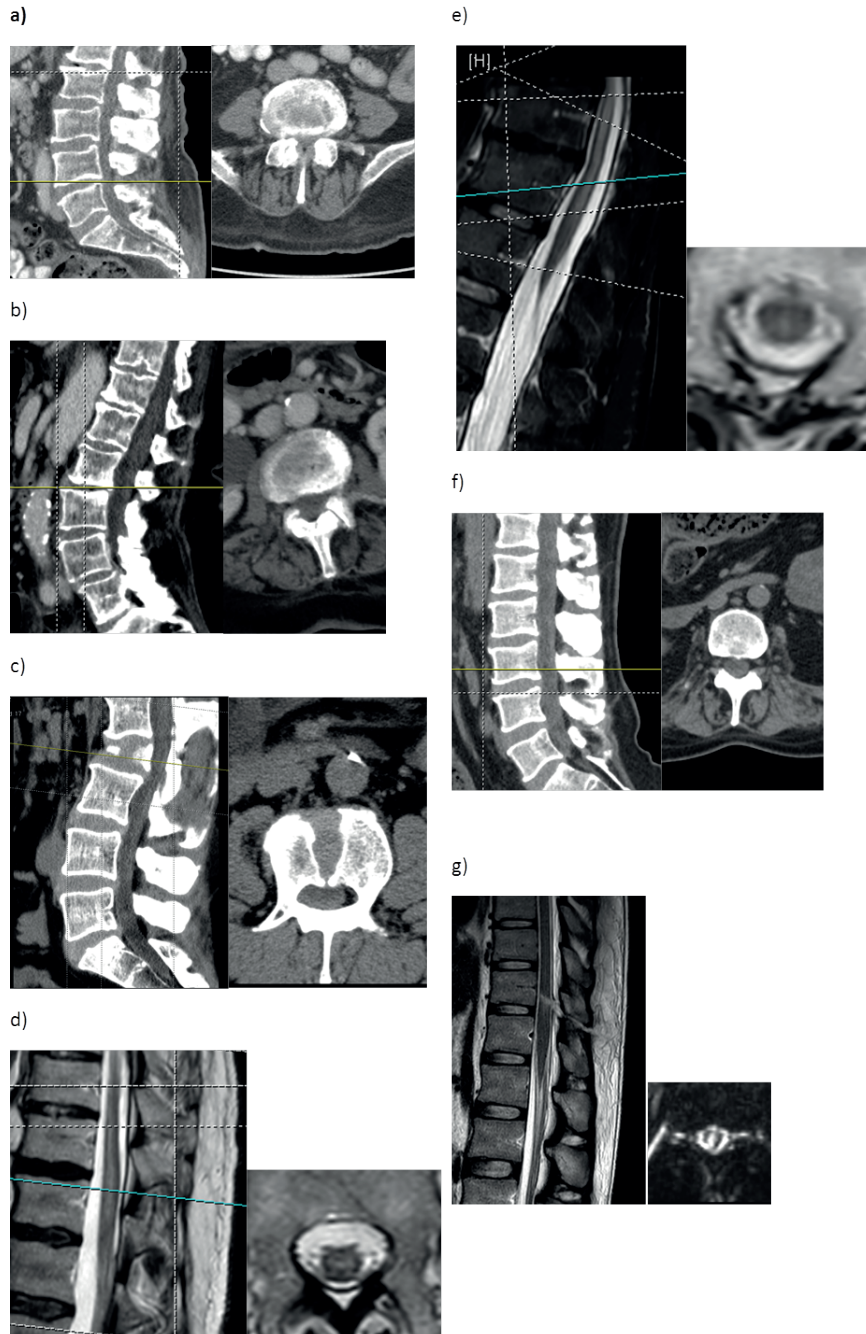
Fig. 1. Examples of radiographs. (a–e) Suspected damage to lumbar spinal cord and roots (LSCR). (f–g) No damage to LSCR. (a, b) Degenerative changes affecting foramina. (c) L2 fracture in a person with a traumatic cervical SCI. (d) Spinal infarction from vertebral levels T10 to T12. (e) Previous intraspinal lumbar bleeding from a suspected mycotic aneurysm at the cervical and high thoracic levels. The magnetic resonance image (MRI) shows oedema in the spinal cord stretching down to the lumbar spinal cord. (f) Normal spine. (g) Knife wound at spinal cord segment T11 with no distal damage to the LSCR.

Spasticity was defined according to Pandyan et al. (9) as any involuntary muscle activity in the legs, as reported by the patient. Spasticity was considered troublesome where it interfered with daily life or where pharmacological treatment was deemed necessary. Sixty-nine patients received some sort of anti-spastic pharmacological treatment, e.g. oral baclofen ($n=31$), oral diazepam ($n=14$), intrathecal baclofen ($n=11$) and/or botulinum toxin ($n=36$).

Pain was analysed as either nociceptive or neurogenic according to Bryce et al. (10). Neurogenic pain was further categorized into peripheral, BLSCIN, and mixed pain. BLSCIN pain is located at least 3 segments below the level of injury and not according to the distribution of a nerve root or peripheral nerve. BLSCIN pain should not be aggravated by physical activity and, in the current study, questions were limited to pain in the lower trunk or legs. Sixty-four patients had BLSCIN pain. The

pharmacological treatment of BLSCIN pain followed a stepwise pattern. Gabapentin, pregabalin or clonazepam were given to 32 patients and, where this was insufficient, amitryptiline, nortriptyline or duloxetine was prescribed to 18 patients. Nineteen received opiate treatment.

Interviews took place between 2014 and 2019. The statistical significance of differences in the prevalence of spasticity and pain was tested using the χ^2 test Fisher exact test. Dependence on background factors was analysed by logistic regression (SPSS version 22) and statistical significance was set to $p < 0.05$ in all analyses.

The retrospective chart review was approved by the local ethics committee M2 (number 375-16).

RESULTS

Influence of damage to lumbar spinal cord and nerve roots

Of all 269 patients, 74% experienced spasticity, 45% found their spasticity troublesome and 28% reported BLSCIN pain (**Table I**). Damage to LSCR was found in 108 of the patients. These patients had a lower frequency of spasticity (55%) compared with those without damage (86%), whereas the frequency of BLSCIN pain was approximately the same. Binary logistic regression of the results for all 269 patients showed that spasticity, but not BLSCIN pain, had a significant and strong association with the absence of damage to LSCR (**Table II**).

Dependency on spinal level

The frequency of both spasticity and troublesome spasticity in the whole group ($n = 269$) appeared to be less frequent in cases where the SCI was at a lower thoracic level. This is demonstrated by the regression line in **Fig. 2** left diagram) and is in contrast to BLSCIN pain frequency, which was unaffected by segmental level of the SCI. On the other hand, this segmental relation was not present where only patients without damage to LSCR were included (Fig. 2, right diagram). Of these 161 patients, 87% of those with cervical SCI and 85% of those with thoracic SCI experienced spasticity. The corresponding figure for troublesome spasticity was 54% and 50%. A binary logistic regression of the group of patients without damage to LSCR showed that segmental level did not significantly influence these frequencies (**Table III**).

Association between spasticity and below-level spinal cord injury neuropathic pain

The association between spasticity and BLSCIN pain was tested in the group with no signs of damage to LSCR

Table II. Binary logistic regression of the 3 outcomes in the whole group ($n = 269$). Variable(s) entered in step 1: damage to lumbar spinal cord and roots (LSCR), spinal cord segment, American Spinal Cord Injury Association Impairment Scale (AIS), traumatic injury, male sex, present age and years since injury. Reference AIS is AIS D.

	p-value	Exp(B)	95% CI for Exp(B) Lower	Upper
Spasticity				
LSCR damage	0.001	0.309	0.160	0.600
Spinal cord segment	0.095	0.951	0.897	1.009
AIS	0.048			
AIS A	0.306	1.527	0.679	3.438
AIS B	0.080	6.629	0.799	54.981
AIS C	0.020	3.330	1.209	9.173
Traumatic injury	0.120	1.785	0.860	3.706
Male	0.408	1.347	0.665	2.727
Current age	0.193	0.987	0.968	1.006
Years since injury	0.289	1.014	0.988	1.041
Constant	0.031	4.887		
Troublesome spasticity				
LSCR damage	0.121	0.629	0.350	1.130
Spinal cord segment	0.040	0.947	0.898	0.997
AIS	0.013			
AIS A	0.385	1.357	0.681	2.705
AIS B	0.026	3.022	1.142	7.996
AIS C	0.005	3.186	1.412	7.189
Traumatic injury	0.263	1.471	0.748	2.893
Male	0.412	1.297	0.697	2.416
Current age	0.522	0.994	0.978	1.011
Years since injury	0.199	0.987	0.967	1.007
Constant	0.847	1.129		
Below-level spinal cord injury neuropathic pain				
LSCR damage	0.407	0.759	0.396	1.456
Spinal cord segment	0.422	1.023	0.967	1.083
AIS	0.322			
AIS A	0.192	1.646	0.779	3.479
AIS B	0.228	1.866	0.677	5.142
AIS C	0.102	2.025	0.869	4.719
Traumatic injury	0.051	2.152	0.997	4.646
Male	0.919	0.965	0.491	1.899
Current age	0.235	1.011	0.993	1.030
Years since injury	0.007	0.969	0.947	0.992
Constant	0.004	0.128		

LSCR: lumbar spinal cord and roots.

Table III. Binary logistic regression of the outcomes in the group without damage to lumbar spinal cord and roots (LSCR) ($n = 161$). Variable(s) entered on step 1: spinal cord segment, American Spinal Cord Injury Association Impairment Scale (AIS), traumatic injury, male sex, present age and years since injury. Reference AIS is AIS D.

|	*p*-value	Exp(B)	95% CI for Exp(B) Lower	Upper
Spasticity				
Spinal cord segment	0.601	0.975	0.887	1.072
AIS	0.105			
AIS A	0.276	1.845	0.613	5.554
AIS B	0.071	7.403	0.843	64.976
AIS C	0.068	7.284	0.862	61.540
Traumatic injury	0.547	1.453	0.431	4.901
Male	0.353	1.649	0.574	4.740
Current age	0.485	0.987	0.952	1.023
Years since injury	0.629	0.991	0.955	1.028
Constant	0.166	4.706		
Troublesome spasticity				
Spinal cord segment	0.677	0.985	0.917	1.058
AIS	0.020			
AIS A	0.155	1.858	0.790	4.370
AIS B	0.013	3.909	1.332	11.468
AIS C	0.010	4.462	1.423	13.991
Traumatic injury	0.765	1.164	0.430	3.155
Male	0.932	1.037	0.454	2.367
Current age	0.458	1.010	0.984	1.036
Years since injury	0.012	0.966	0.941	0.993
Constant	0.588	0.637		

95% CI: 95% confidence interval.
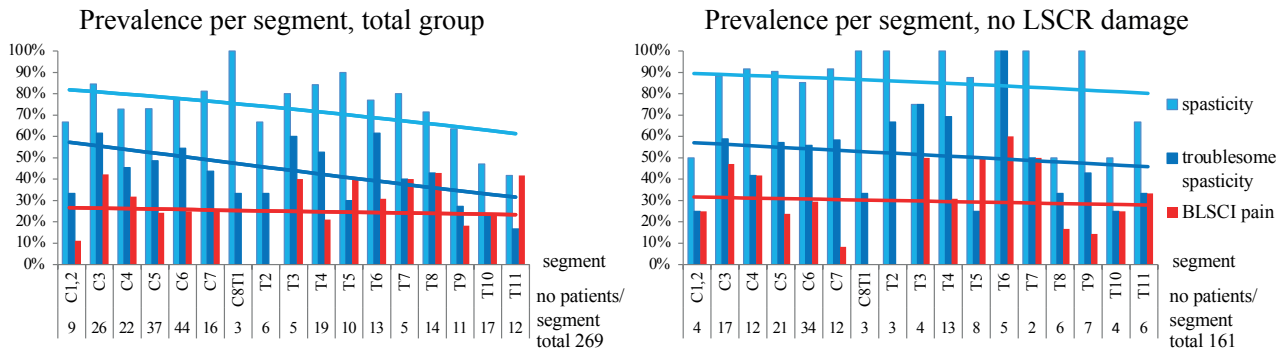
Fig. 2. Relative prevalence among patients with lesions at different spinal cord segments. Logistic regression line shown for each outcome. LSCR: lumbar spinal cord and roots; BLSCIN: below-level spinal cord injury neuropathic.

(**Table IV**). Neither spasticity nor troublesome spasticity was associated with BLSCIN pain.

DISCUSSION

This study shows that patients with a cervical or thoracic SCI concurrent with signs of damage to LSCR have a lower prevalence of spasticity. As expected, no such association was found for BLSCIN pain. In the group without damage to LSCR, the SCI level had no significant effect on spasticity, troublesome spasticity and BLSCIN pain. Spasticity and BLSCIN pain were not associated.

This cohort appears to be representative; the prevalence of spasticity or BLSCIN pain was similar to the previous studies (3, 4, 11, 12). The prevalence of BLSCIN pain may have been underestimated, as evoked neurogenic pain was not included. The prevalence of spasticity may also have been underestimated, as patients experiencing muscle stiffness may have given negative answers to questions regarding involuntary muscle activity. Finnerup (13) advocates more detailed investigations regarding spasticity and pain descriptors. Radiological determination of vertebral damage was estimated visually and was therefore necessarily subjective. This may have resulted in an underestimation of degenerative changes in the spine. There is no universally accepted definition as to

when a foraminal stenosis is to be considered significant, and most studies prefer to measure the height using sagittal images. This measurement should preferably be carried out with the patient in a sitting position. The best method for finding evidence of damage to LSCR may be neurophysiological. In patients with lumbar stenosis, Lee & Lee (5) found that the results of electromyographic tests in leg muscles were more closely correlated with leg weakness than damage found in MRI examinations of the lumbar spine. Perhaps all of the patients in this study with AIS A to AIS C, and without spasticity, had some degree of LSCR damage. It is possible that neurones in motor pathways will develop overactivity in all patients with a substantial SCI above the motor neuronal level.

Since no association was found between spasticity and BLSCIN pain, they appear not to share common mechanisms, such as a general predisposition to develop neuronal overactivity after central nervous system (CNS) damage. The drugs that reduce spasticity and BLSCIN pain are also different: baclofen the main drug used for depressing spasticity has only a minor effect on BLSCIN. Correspondingly, the main drugs used for BLSCIN pain gabapentinoids or tricyclic antidepressants have only minor effects on spasticity (see Finnerup (13) for references). It therefore seems justified to discuss spasticity and BLSCIN pain separately.

The segmental level of the SCI in the group with no damage to LSCR was found to bear no relation to spasticity. This implies that very few neurones in spinal segments higher up (below the SCI but above the lumbar segments) contribute to leg spasticity. It also suggests that the neurones contributing to leg spasticity are located within the lumbar or sacral segments; this could be the motor neurones or lumbar/sacral interneurones (Fig. 2). Jankowska & Hammar (2) discusses possible interneuronal reflex arcs contributing to spasticity: since alpha-2 adrenergic agonists have an antispastic effects in patients with SCI and that the depressive effects of these agonists is mainly on group II interneurones and not on the motor neurones, they argue for interneuronal overactivity as a major cause for spasticity.

Table IV. Differences in prevalence of spasticity and below-level spinal cord injury neuropathic (BLSCIN) pain tested using χ^2 test (Fisher's exact test). Results for the group without damage to lumbar spinal cord and roots (LSCR) ($n = 161$). Table shows the number of patients with spasticity and BLSCIN pain

	BLSCIN pain		Fisher's test
	Yes	No	
Total, n (%) [95% CI]	49 (30) [23–38]	112 (70) [62–77]	
Spasticity, n (%) [95% CI]	43 (31) [23–39]	96 (69) [61–77]	
No spasticity, n (%) [95% CI]	6 (27) [6–48]	16 (73) [52–94]	$p = 0.8$
Troublesome spasticity, n (%) [95% CI]	28 (33) [22–44]	57 (67) [56–78]	
No troublesome spasticity, n (%) [95% CI]	21 (28) [17–38]	55 (72) [62–83]	$p = 0.5$

95% CI: 95% confidence interval.

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Since BLSCIN pain (experienced below the SCI level) is also present in complete SCI, some of the neural alterations must be localized above the lesion. It is considered that BLSCIN pain requires a lesion of the spinothalamic tract and may be caused by neuronal overactivity at several levels in the spinal cord and brain, including in the thalamus. If BLSCIN pain was dependent only upon a lesion of the spinothalamic tract, then a cervical SCI should cause a more extensive deafferentation in the thalamus compared with a lower SCI. However, BLSCIN pain was not more prevalent in cases of cervical SCI. The lack of correlation between segmental level and pain could be explained by overactivity in neurones located just above the SCI. Vierck (14) suggests that BLSCIN pain is caused by a combination of different neural mechanisms. He suggests that the main mechanism is damage to pathways from the dorsal horn to reticular nuclei in the brainstem. This system is considered to consist of chains of propriospinal interneurons conveying impulses from C-fibre afferents, impulses that are experienced as diffuse widespread pain.

The lower prevalence of spasticity in patients with LSCR damage points to the possibility that degeneration of the lumbar spine contributes peripheral paresis on top of the central paresis of the legs in elderly patients. This study also suggests that future studies of the neuronal mechanisms behind spasticity should mainly be directed to the lumbar segments. The suggested localization of a pain generator just above the level of the SCI supports further investigation into the use of intrathecal gabapentin. Previous attempts by Rauck et al. (15) to treat peripheral neuropathic pain with intrathecal gabapentin failed, but further study is warranted into the effect on BLSCIN pain of intrathecal gabapentin injection just above the level of the SCI.

ACKNOWLEDGEMENTS

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