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Original Article

Segmental muscle innervation as a basic anatomo-physiological knowledge for diagnostic procedure of neuromuscular disorders and thus, a way for accurate EMG diagnosis of single root injury. Retrospective study in patients with radicular symptoms

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Abstract

Background: An accurate identification of the injured nerve roots by EMG in patients with symptomatic CSD requires that the examined muscles are innervated by a single nerve root. In the present retrospective study, the authors address the question of whether such innervation of chosen muscles in the upper extremity can be identified.

Methods: Scored EMG results of chosen muscles with the hypothesized innervation by C6, C7 or C8 nerve roots, collected from 42 patients, were compiled as single EMG *variables* and compared with the respective MRI data, possibly responsible for injury of those roots, using *Spearman's rho* (SRC) analysis. Subsequently, each EMG variable was adopted as specific diagnostic *method* for single root injury and tested for its *specificity* and then *sensitivity* in relation to the data of the highest ranked MRI, used as a '*gold standard method*'

Results: SRC results showed positive rank correlation, with the highest p-values, between EMG and the respective MRI variables, in 64 included extremities. Consequently, the assumed EMG-C6, -C7 and -C8 *methods* showed a high specificity (97% - 100%) against the respective highest ranked MRI. The relative sensitivity of the EMG methods calculated in this way were 38% for the C6-root, 87% for the C7 and 50% for the C8.

Conclusions: The results corroborate the presumed innervation of the chosens muscles by single C6, C7, or C8 nerve root, thus allowing the use of needle EMG examination of those muscles for accurate identification of injured single nerve roots in patients with symptomatic CSD.

Background

Symptomatic cervical spine disorder (CSD), clinically manifested as radiculopathy, is a complex progressive degenerative disorder of the cervical spine, that often causes abnormality of the nervous structure in the area. If localization and severity of the injury are well defined, surgical intervention can be helpful. Severe compression of the nerve roots causing axonal degeneration (AD) can be detected merely by EMG examination. An accurate identification of a single injured root requires that EMG abnormality of the examined muscle is specifically related to the injury only of that single nerve root. In other words, one muscle, or its separate heads, should be innervated by a single nerve root, mono-segmentally, and thus belong to a single myotome. However, the published so called 'myotome charts' listing segmental innervation of the limb muscles, as derived from different sources, suggest each muscle as being innervated by two or three adjacent nerve roots. [1-4]. Discrepancies between the results of different examination methods were reported. Consequently, using those charts, an accurate diagnosis of the injured single nerve root by EMG is not possible, regardless of the number of examined muscles or EMG criteria used [5,6].

At the same time, the personal clinical and electrophysiological experience and observations, of the first author, [7,8] in line with the 'predominate muscle innervation' suggested by Inman and Sounders [9], support the concept that muscles, or their separate

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heads, indeed, might be innervated by a single nerve root. That became a working hypothesis of the present retrospective study aimed, by using statistical models, to re-evaluate nonspecific EMG examination as a specific method for accurate diagnosis of single root injury. Similar studies and similar approach have not been carried out and published before.

Methods

The material included 42 patients clinically diagnosed as symptomatic CSD, (24 men, 18 women, mean 44 years, range 28–59 years), participated in the previous study of our group [7], and being under consideration for possible treatment at the Department of Neurosurgery at the University Hospital of Northern Sweden. The patients had heterogeneity of acute or chronic symptoms and signs indicating involvement of one or more cervical nerve roots [7]. However, clinical picture was not the subject of the current study. All were cleared from other neurological disorders at the initial clinical examination and referred to electrophysiological one and MRI by one of the authors (H.H.), a specialist in physical medicine and rehabilitation. Performed EMG and presence of MRI abnormalities at least at one cervical level were the inclusions criteria to the study.

MRI. For each cervical spine level and side, the degree of narrowing of the spinal canal (anterior part) and intervertebral foramen ('root channel') was assessed as no compression (0), 10-30% compression (1), 30-60% (2), and for more than 60% (3), as compared to the adjacent or contralateral level defined as normal. All MRIs were interpreted and scored by an experienced specialist in neuroradiology, a co-author of the present study (MF), independently and prior to EMG examination..

Concentric needle EMG examination, as a part of the routine clinical electro-diagnostic procedure for suspected radiculopathy, was performed and interpreted according to international standards by the first author, an experienced neurophysiologist (OKR), blinded to the results of MRI. EMG patterns of denervation and re-innervation of each muscle were rated as normal (0), mild neurogenic lesion (1), moderate (2), or severe (3) which included both acute and chronic EMG criteria of abnormality. Routinely, abnormal findings on the symptomatic side also initiated EMG examination of the corresponding contralateral muscles..

Applied statistical evaluation

NNeither used diagnostic EMG criteria, nor patterns of identified EMG abnormality of single muscles themselves, are specifically related to any clinically defined "disorder" ('single root injury', in the context of the present study), but - to some physiological processes. Besides, MRI findings presented in the Table 1, and in the previous study [7], clearly demonstrated multiple structural abnormalities on MRI and thus, possible root injury at more than one cervical level in the same person. Hence, in order to evaluate possible specific relationships between EMG results of the examined muscles and injury of a single nerve root, suspected by MRI findings, innervation of each of the chosen easily identified muscles by a single cervical nerve root was hypothesized.

Thus, the muscles: *Supraspinatus* or *Infraspinatus*, anterior and lateral heads of Deltoid muscle, Biceps and *Brachioradialis*, - all those were assigned to innervation by C6 root; the lateral and medial heads of Triceps muscle - as innervated from C7 root. Subsequently, the Flexor *pollicis longus*, or Extensor *indicis proprius* in combination with the First dorsal *interosseous* and Abductor *digiti quinti* were assigned to C8 root innervation. In this way, each of three groups of muscles should also belong to only one of the C6, C7 or C8 myotome.

The rated EMG data of muscles from each single myotome were specified as EMG-C6, EMG-C7 and EMG-C8 *variables*; the scored highest grade of EMG abnormality was accepted as a grade of abnormality for the entire variable. If two or more EMG variables from the same extremity were found abnormal, then, in agreement with the working hypothesis, that was interpreted as injury of two, or more nerve roots.

Similarly, the rated MRI data from selected cervical structures, which were: corresponding and adjacent root channels and anterior impingement of the spinal cord at the levels above the root channels, were adopted as separate respective MRI variables. Each EMG and MRI variable named a separate column in the table where each row included individual continuous data of the scored results from a single extremity.

Subsequently, a nonparametric statistic test - *Spearman rank correlation coefficient* (SRC), also called Spearman's rho, was applied for evaluating whether the ranks of each of the EMG-C6, -C7 and -C8 variables correlated with the ranks of adopted MRI variables possibly responsible for a single root injury. This test should reveal pairs of EMG and MRI variables with the highest Spearman's rho (can be denoted as 'pairs of specific variables'). A probability level of $p \leq 0.0001$ was used throughout to indicate statistically significant positive or negative correlations. All positive and negative EMG and MRI results were included into the analysis where negative (normal) data served as normal controls. This procedure should confirm whether the hypothesized innervation of muscles from each variable/myotome by a single nerve root was correct. Since two or more nerve roots might be involved in the same patient, which could influence SCR results, specificity testing is particularly relevant.

Next, each pair of specific EMG and MRI variables was adopted and evaluated as a pair of *methods* for potential diagnosis of one particular C6, C7 or C8 nerve root injures. For this purpose, each of the EMG-C6, EMG-C7 and EMG-C8 methods was tested for its *specificity* and then *sensitivity* in relation to the results of the corresponding highest ranked MRI data, adopted as a 'gold standard *method*'- a 'method which defines the disorder' (structural abnormalities of the cervical spine, in the context of the present study). Specificity was

Table 1. *Foramina (root channels) abnormality on MRI of 42 patients with symptomatic CSD*

Foramina involved on MRI	Number of sides
C4-5	3
C5-6	16
C6-7	1
C4-5; C5-6	4
C4-5; C6-7	1
C5-6; C6-7	22
C4-5; C5-6; C6-7	7
C4-5; C5-6; C7-Th1	1
C5-6; C7-Th1	1

estimated as a percentage of all normal (i.e., negative) results of the respective MRI method correctly identified an absence of root injury by the corresponding EMG (the *True negative* EMG results). Since two or more nerve roots might be involved in the same patient, which could influence SCR results, specificity testing (correct identification of the injured root by the EMG method) is particularly relevant. A method with low specificity (many *False positive* EMGs) is less, or even not at all reliable, and its sensitivity, may be of no importance.

The last test, was an assessment of sensitivity of each adopted EMG-C6, EMG-C7 and EMG-C8 methods. The sensitivity was calculated as a percentage of all positive (i.e., abnormal) MRI results correctly identified as abnormal by the corresponding highest ranked EMG (*True positives* EMG).

Comment. As testing of specificity also reveals *False positive* EMG results, being not included into the following estimation of sensitivity of the method, it might be valuable for clinical and diagnostic purposes to explain their underlying causes. False positivity may depend on a higher sensitivity of the index method (EMG) compared to that of the reference one (MRI), using other diagnostic criteria, or - on different origins of abnormality (injuries of different roots, in the present study) detected by EMG and MRI. In both situations, the reason is an incorrectly chosen gold standard method.

Results and discussion

The results of Spearman's rho test, performed for EMG and MRI variables (obtained from 64 extremities of 42 patients), are presented in the Table 2. It shows statistically significant the highest correlation between the ranks of EMG-C6, EMG-C7 and EMG-C8 variables and the respective MRI data: C5-6 (C6 root), and C6-7 (C7 root) foramina narrowing, as well as impingement of the spinal cord at the C5-6 level (C8 root).

The subsequent specificity testing of EMG methods, showed that no abnormal EMG-C6 results were present without a corresponding abnormality of the channel for C6 root on MRI (100% specificity). Only two among the 29 abnormal EMG-C7 were found without narrowing of the related C6-7 foramen (C7 root channel) on MRI (97% specificity). In those two false positivity, abnormal EMG findings might be a result of anterior compression of the spinal cord at the C5-6 and C6-7 levels by the disks, recorded on MRI, which might compress C7 root causing AD.

In our material, the C7-Th1 foramina (i.e., channel for C8 nerve root) was involved only in one patient (Table 1), while mild to moderate EMG abnormalities in muscles of the presumed C8 myotome were found in 15 extremities. The statistically significant highest correlation between the ranks of EMG-C8 variable and the narrowing of the C5-6 spinal canal area on MRI was recorded by SRC analysis (Table 2.) The following specificity testing for EMG-C8 method showed 100% (no *false positives)*. However, in only half of the cases with the anterior compression of the spinal cord at the C5-6 level on MRI, EMG-C8 method was abnormal (50% sensitivity). A similar correlation of abnormal EMG in hand muscles of patients with a spondylotic high cord compression was reported by Stark et al., [10]. Ischemia caused by vascular compromise, as a cause for cell death of the motor neurones of distal muscles (most laterally located within the anterior horn at that cervical level) was an accepted possible explanation of the phenomenon suggested by Brain et al., [11]. Anatomically, the motor neurones of the distal muscles are known to be the most laterally located within the anterior horn at that cervical level. This should emphasize the necessity of careful analysis and consideration of MRI abnormalities at all cervical levels when evaluating radiculopathies.

Table 3 shows that abnormality of different MRI structures was observed more often at the C5-C6 than that at the C6-7 level, while positive EMG-C7 (C7 root injury) was, on the contrary, recorded more often than EMG-C6 (C6 root), meaning that C7 root compression, although less frequent, is usually more severe. That resulted in a lower diagnostic sensitivity of the EMG-C6 than EMG-C7 method: 38%, and 87% respectively. The findings might be explained by individual anatomical conditions, as well as by protrusion of the largest C6 disk within C6-C7 root channel [12] usually causing AD of the ventral C7 root, detected by EMG. Compared to this, degenerative changes at the C5-6 level on MRI are, most likely, a result of a slowly developing process which can start asymptomatically already at the earlier age [13]. The mentioned differences in the incidence and severity between C6 and C7 root injuries diagnosed by EMG and MRI, made it possible for SRC analysis to separate variables with the highest correlation of ranks in conditions when two or more nerve roots were involved in the same patients.

As the selected muscles assigned in this study to C6 innervation are often listed in published myotome charts

Table 2. *Results of Spearman rank correlation between EMG and MRI.*

EMG	MRI	p
C6	Foramina C5-6	< 0.0001
C7	Foramina C6-7	< 0.0001
C8	Spinal cord C5-6	< 0.0001

Table 3. *Relative incidences of abnormal segmental findings by MRI and EMG diagnosed C6 and C7 root injuries, compiled for 42 patients with symptomatic CSD. The higher values, compared to the other level, are presented as bold numbers.*

Segment		**Relative incidences of abnormality**				**Sensitivity**
Roots	*Clinical dermatome*	**EMG**	**MRI structures**			**EMG / Foramina**
			Disk	*Spinal cord*	*Foramina*	
C5-6 (C6)	n = **19**	n = 29	**37%**	**52%**	**76%**	38 %
C6-7 (C7)	n = 16	n = **47**	27%	34%	54%	**87 %**

as having supplementary, or even solely, C5 innervation, specificity of EMG-C6 method was also tested against the narrowing of C4-5 root channel. However, in 12 of the 17 cases with abnormal EMG-C6, C4-5 foramina on MRI (possible C5 root injury) was normal (30% specificity). False positivity could conceivably be explained by the co-involved C5-6 level on MRI in those cases, in relation to which abnormal EMG-C6 were true positive. Thus, a presence of innervation by C5 nerve root of the chosen muscles, with the presumed C6 innervation, could not be confirmed, but neither excluded in the present study.

Conclusions

The hypothesis of innervation of the chosen muscles by single C6, C7 or C8 nerve roots, and, accordingly, their belonging to respective single C6, C7 or C8 myotome, was statistically confirmed in this retrospective study on 42 patients with symptomatic CSD. The results of Spearman's rho analysis were subsequently supported by the obtained high specificity of the EMG results correlated to corresponding MRI data of the cervical structures. Structural abnormalities on MRI responsible for injures of single cervical roots have also been distinguished.

The usefulness of this important fundamental knowledge of muscle innervation and its relation to the MRI results is that EMG examination of the selected muscles can be applied in patients with symptomatic CSD for specific diagnosis of single injured C6, C7 or C8 root with an accuracy of one segment, which is especially important when surgical procedure within the cervical area is under consideration. However, diagnostic applicability of each specific EMG evaluation in practice varied for different nerve roots, due to varying grades of injury of single nerve roots and, thus, lower sensitivity of diagnostic EMG criteria compared to MRI.

Similar studies have not been carried out or published before, and neither similar statistical approach nor similar results have been presented.

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