Research article/Raziskovalni prispevek

PLANNING THE MICROSURGICAL MYELOTOMY IN INTRAMEDULLARY TUMORS OR CYSTS BY INTRAOPERATIVE NEUROMONITORING

IZBIRA MIKROKIRURŠKE MIELOTOMIJE PRI OPERACIJAH TUMORJEV IN CIST V HRBTENJAČI S POMOČJO INTRAOPERATIVNEGA NEVROMONITORINGA

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Key words: *spinal cord; dorsal horn damage; dorsal columns damage; somatosensory potentials; functional anatomy; myelotomy planning*

Abstract – Background. *Surgical approach to the intramedullary tumors and cavities are microsurgical techniques of dorsal myelotomies, which entails the risk of damage to the dorsal columns and the central spinal cord gray matter. The aim of the study is to analyze the clinical sensory dysfunction before surgery and the changes of the intraoperative SEP (somatosensory potentials) before myelotomy. These data would be of help to neurosurgeons in planning the myelotomy – dorsomedial or dorsolateral.*

Methods. *16 patients were operated on for deafferentation pain syndromes, intramedullary tumors and syringomyelia of the cervical spinal cord. Preoperatively the patients sensory system of dorsal columns and central gray matter was examined for vibration and position sense dysfunction and pain and temperature damage. Before myelotomy the intraoperative SEP from the dorsal surface of the spinal cord after the stimulation of the median and tibial nerves were recorded.*

Results. *After median nerve stimulation the N13 wave was partially or completely absent, and fast negative waves appeared instead. The presence and absence of N13 was in association with pain and temperature dysfunction or with dissociative sensory loss. The mean duration of the SEP potential was shorter than normal ($p < 0.0005$, $n = 11$). After tibial nerve stimulation the first negative waves were most stabile, fast negative waves as the most prominent element of the normal SEP were partially or completely absent. This change was in association with diminution or loss of vibration and posture senses. The duration of the conductive SEP was shorter than normal ($p = 0.064$, $n = 5$).*

Conclusions. *Dissociative sensory loss is associated with absence of the N13 in median nerve SEP and connected to the central cord destruction. The loss of vibration and posture senses affects the fast negative waves of tibial SEP and points toward damage of the dorsal columns. The dorsolateral myelotomy is justified in cases of central cord destruction, and dorsomedial myelotomy in cases of dorsal columns damage.*

Ključne besede: *hrbtenjača; okvara zadnjega roga; okvara zadnjih stebričkov; somatosenzorični potenciali; funkcionalna anatomija; izbira mielotomije*

Izvleček – Izhodišča. *Klinični simptomi in znaki intramedularnih tumorjev in siringomielije večinoma ne dajejo dovolj podatkov za natančno oceno poškodbe živčnih celic zadnjega roga in živčnih vlaken zadnjih stebričkov. Slike hrbtenjače z magnetno resonanco (MR) pokažejo mesto cistične votline ali tumorja v hrbtenjači, vendar ne dajejo informacij o položaju spremembe glede na dolge senzorične proge in zadnje rogove ter ne omogočajo ocene motenj prevajanja živčnih dražljajev v hrbtenjači. Odstranjevanje tumorjev in cist hrbtenjače omogočajo dorzalne mielotomije, ki nosijo tveganje poškodbe zadnjih stebričkov in centralne sivine hrbtenjače. Zato je potrebno objektivno funkcionalno spremljanje delovanja anatomskih predelov hrbtenjače, ki so najbolj izpostavljeni pri odstranjevanju intramedularnih sprememb. Rezultati naše predhodne študije so pri intramedularnih tumorjih in siringomieliji pokazali spremembe elementov somatosenzoričnih evociranih potencialov (SEP), registriranih s pomočjo intraoperativnega nevromonitoringa. Namen prispevka je ugotoviti funkcionalno poškodbo teh delov hrbtenjače s pomočjo senzoričnih izpadov pred operacijo in sprememb elementov intraoperativnih SEP registriranih na hrbtenjači pred mielotomijo. Podatki bi pomagali pri odločitvi za vrsto mikrokirurške mielotomije – za dorzomedialno ali za dorzolateralno mielotomijo.*

Metode. *Podatke smo zbrali pri 16 bolnikih, operiranih zaradi deaferentacijske bolečine (5 bolnikov), intramedularnih tumorjev (5 bolnikov) in siringomielije (6 bolnikov) hrbtenjače. Meritve pri bolnikih z bolečinskim sindromom smo izbrali za normalne podatke, ker niso imeli nevroloških izpadov v distribucijskem področju stimuliranih perifernih živcev. Pred operacijo smo klinično preverili senzorični sistem zadnjih stebričkov in centralnega dela hrbtenjače s preiskavo občutkov za vibracije in položaj sklepov ter bolečine in temperature. Vse bolnike smo operirali v splošni anesteziji. Pri bolnikih smo opravili intraoperativni nevromonitoring SEP z registracijsko elektrodo, nameščeno neposredno na sredino zadnje površine hrbtenjače in po električni stimulaciji medianih in tibialnih živcev. Registracijo SEP smo opravili še pred mielotomi-*

These functional anatomic informations are helpful in planning the myelotomies in cases of intramedullary tumors and syringomyelia.

jo in pred odstranitvijo intramedularnega tumorja ali drenažo ciste.

Rezultati. *V distribucijskem področju stimuliranih perifernih živcev je imelo 8 bolnikov oslabljene ali odsotne občutke za temperaturo in bolečino (disociacija senzibilitete), 6 bolnikov je imelo okvaro občutkov za vibracije in položaj sklepov, pri 3 bolnikih pa so bile okvarjene vse štiri senzorične kvalitete. Po stimulaciji medianega živca je bil val N13 delno ali popolnoma odsoten, kar je bilo povezano z motnjo občutka za bolečino in temperaturo. Pri enostranski odsotnosti vala N13 je bila disociacija senzibilitete blažja, pri obojestranski odsotnosti sta bila občutka za temperaturo in bolečino praviloma izgubljena. Namesto vala N13 so postali izraziti HNV (hitri negativni valovi). Trajanje odziva pri bolnikih je bilo pomembno krajše kot pri normalnih ($p < 0{,}0005$, $n = 11$). Po stimulaciji tibialnega živca so bili pri bolnikih najbolj zanesljivi začetni negativni valovi, HNV kot najizrazitejši element normalnih odzivov pa so izgubili vretenasto obliko ali bili odsotni. HNV so bili bolj spremenjeni pri okvarah občutka za vibracije in položaj sklepov. Trajanje odziva je bilo neznačilno krajše kot pri normalnih ($p = 0{,}064$, $n = 5$).*

Zaključki. *Čeprav diagnoza intramedularnih tumorjev in siringomielije hrbtenjače sloni na slikovnih tehnikah, kot je MR, nam te tehnike ne ponujajo informacij o delovanju hrbtenjače v predelih, kjer je potrebno operirati. Bolniki z disociacijo senzibilitete, kot je to pri siringomieliji, imajo odsoten val N13, kar kaže na poškodbo centralnih delov hrbtenjače. Asimetrična izguba N13 kaže na enostransko poškodbo zadnjega roga hrbtenjače in usmerja začetno mielotomijo na stran poškodbe. Obojestranska izguba vala N13 kaže na poškodbo centralne sivine in obeh zadnjih rogov hrbtenjače. Pristop skozi DREZ področje (dorzolateralna mielotomija) je v teh dveh primerih boljši kot dorzomediana mielotomija zaradi nedotaknjenih zadnjih stebričkov. Bolniki z okvaro občutkov za vibracije in položaj sklepov imajo spremenjene HNV. To kaže na poškodbo zadnjih stebričkov hrbtenjače. Mikrokirurški pristop v takih primerih intramedularnih sprememb je dorzomedialna mielotomija skozi žleb med zadnjimi stebrički. Povezava kliničnih nevroloških izpadov, sprememb intraoperativnih SEP pred mielotomijo in anatomskega mesta spremembe v hrbtenjači nam daje funkcionalne anatomske informacije. Ti podatki nevrokirurgom pomagajo pri izbiri mikrokirurškega pristopa skozi zadnjo površino hrbtenjače in zmanjšujejo možnost poškodbe delujočega tkiva hrbtenjače.*

Introduction

Clinical signs of intramedullary spinal cord tumors and syringomyelia are often insufficiently informative for assessing the damage caused by tumoral or syrinx compression to neurons of dorsal horn (DH) or to fibers of dorsal columns (DC). MRI, which proved to be helpful for detecting the presence of a cyst (Figure 1A) and outlining the limits of the tumor (Figure 1B), gives no information concerning the position of the lesion in relation to the long sensory tracts and dorsal horns and the dysfunction of spinal cord circuitry. The surgical strategy for the treatment of these tumors and cysts consists of a removal or shunting the cavity using microsurgical techniques of dorsomedial or dorsolateral myelotomy. This procedure entails the risk of DC or DH damage and consequently an immediate postoperative accentuation of the neurological deficits can occur (1–4). Objective intraoperative functional assessment of the spinal cord DC and DH damage is required because these structures are most likely to be damaged during dorsolateral (5) or dorsomedial myelotomy (6, 7). In our previous study in cases of intramedullary tumors and syringomyelia we showed the changes of the elements of intraoperative SEP (8), which enable us to localize the anatomical site of the lesion. Functional anatomic information obtained with intraoperative SEP would be of great help in planning the surgical approach to the spinal cord, i.e. either dorsomedialy between the gracilis fascicles or in the region of DREZ. The dorsomedial approach would be justified if the central gray matter or the DC of the spinal cord would be damaged. The DREZ approach would have clear advantage in cases of asymmetrical dysfunction of the spinal cord gray matter or long tracts.

By presenting intraoperative SEP data aims of the study were to analyze the elements of the intraoperative SEP, which can detect the functional damage to DC fibers and DH neurons, to correlate the clinical sensory dysfunction with changes of the elements of the intraoperative pre-myelotomy SEP, and to establish the important clinical and intraoperative pre-myelotomy SEP elements for intraoperative functional anatomic information. These data would be of great help to operat-

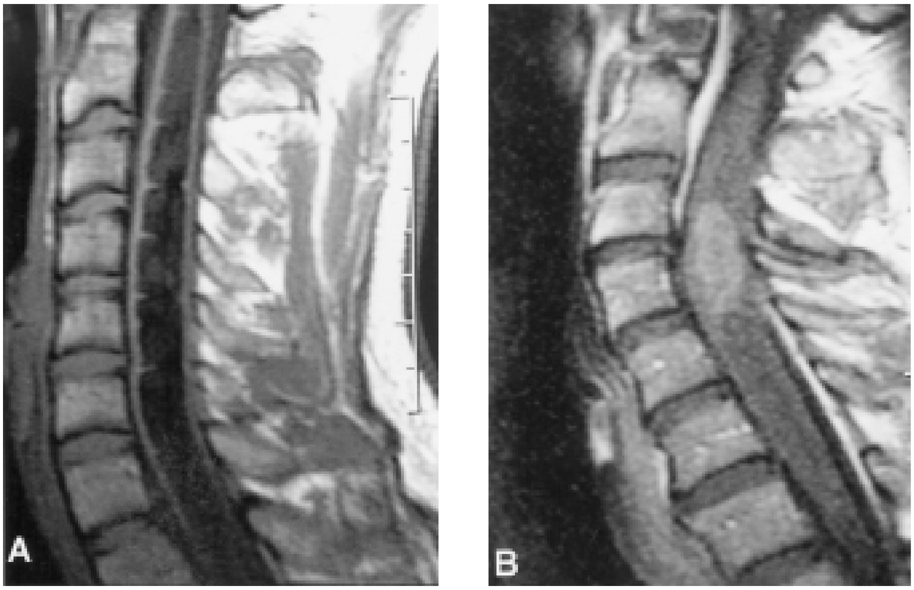

Figure 1. A. *Magnetic resonance image showing cervical syringomyelia. Thin hyperintensive band of functional cord tissue is on the anterior and posterior borders of the syrinx cavity. B. Contrast enhanced round shape intramedullary lesion in the C3 C4 spinal cord segments is showing ependymoma.*

Sl. 1. A. *Slika magnetne resonance vratne hrbtenjače prikazuje siringomielijo vratne hrbtenjače. Le na obodu cistične votline je tanek hiperintenziven pas, ki predstavlja delujoče tkivo hrbtenjače. B. S kontrastnim sredstvom obarvana intramedularna okroglasta tumorska sprememba v višini segmentov C3 C4 vratne hrbtenjače predstavlja ependimom.*

ing neurosurgeons in planning a microsurgical myelotomy in cases of intramedullary tumors and syringomyelia.

Patients and methods

16 patients aged 20 to 68 years (9 males, 7 females) were operated on at our institution for deafferentation pain syndromes (5 cases), intramedullary cervical spinal cord tumors (5 cases) and syringomyelia of the cervical cord (6 cases). MR imaging proved the intramedullary lesions in the patients before the operation (Figure 1A, B). Clinical data of the patients, clinical sensory system dysfunction and characteristics of the electrophysiological somatosensory evoked potentials are presented in Table 1.

All recordings were obtained during intraoperative monitoring of the spinal cord function and before myelotomy. The recordings in 5 subjects undergoing DREZ coagulation for pain relief were considered normal because the subjects didn't have any neurological deficit in the distribution territory of the stimulated nerves. Median and tibial nerves were stimulated in 11 subjects suffering either spinal cord tumor or syringomyelia. Before operation the sensory system was assessed since the SEP was investigated and the myelotomy in the anatomical region of spinal cord sensory system was made. Pain and temperature senses were diminished or absent, only vibration and posture senses, or all four senses were affected in distribution territories of median and tibial nerves stimulated. Prior to induction of anaesthesia, bipolar surface Nihon Kohden NM-4205 electrodes (Nihon Kohden Corp., Tokyo, Japan) were placed over the median nerve at the wrist and over the tibial nerves in the popliteal fossa. Cathode was placed proximally to anode. The ground electrodes were fastened to both forearms and thighs above the stimulation site. For anaesthesia, ventilation with N2O and O2 supplemented with halothane and fentanyl was used, and for muscle relaxation curare analogues (vencuronium) was used. After opening of the dura and the arachnoid the dorsal surface of the spinal cord was exposed. Medtronic Piscess-Sigma electrodes (Medtronic Inc., Minneapolis, MN, USA) were applied directly to the dorsomedian sulcus of the spinal cord under higher magnification of the operating microscope. If necessary, electrode position was adjusted by means of microsutures to the arachnoid. Before approaching the spinal cord lesion SEP were recorded directly from the exposed segments of the spinal cord, resulting in two recordings per nerve stimulated. A needle electrode inserted into paraspinal musculature between the upper and the lower electrodes served as reference. Recording and reference electrodes resistance was below 2 kO. For monitoring, a Nihon Kohden Four Mini MEB-5304K unit was used. Stimulation was applied alternately to both sides in all subjects except those undergoing DREZ coagulation. In the latter only the median nerve on the unaffected side was stimulated. Square-wave pulses of 0.3 ms duration, with a frequency of 10 Hz and intensity three to five times the motor threshold were used. The recording bandpass filter setting was 10 Hz to 3 kHz and analysis time was either 30 or 50 ms. Consecutive responses were averaged 200 times and recordings were repeated twice to assess reproducibility. In order to be able to draw electroclinical associations, only data for nerves with clinically evident damage to the somatosensory system were used in patients. SEP recordings were made before myelotomy for tumor removal or puncture of cystic cavity. In cases of deafferentation pain the method of junctional DREZ microcoagulation was used. In these cases the SEP proximal and distal to the DREZ lesions were recorded. In syringomyelia patients the syringosubarachnoidal shunting after myelotomy was made. Intramedullary tumors were removed with the help of microsurgical technique after myelotomy.

Results

In distribution area of stimulated median and tibial nerves the pain and temperature senses were diminished or absent in 8 patients (5 cases in syringomyelia, 3 cases in intramedullary tumors), the vibration and joint position senses were damaged in 6 patients (4 cases in intramedullary tumors, 2 cases in syringomyelia), and all four sensory modalities were damaged in 3 patients with intramedullary tumors.

Normal median nerve SEP consists of a triphasic high amplitude potential (Figure 2A). Patients median nerve SEP differed from normal SEP. Wave N13 was distorted and partially absent. In some cases N13 wave was completely lost. The presence and absence of N13 was in association with diminution or loss of pain and temperature senses. The loss of N13 was unilateral (Figure 3) in 5 cases (4 cases of syringomyelia and 1 case of intramedullary tumor) and bilateral (Figure 4) in 5 cases (3 cases of intramedullary tumor and 2 cases of syringomyelia). With the former damage to pain and temperature senses was milder than with the latter and dissociative sensory deficit was milder at the same side. Bilateral loss of N13 was usually accompanied by complete loss of pain and tem-

Table 1. *Clinical data of the patients, clinical sensory system dysfunction and characteristics of the electrophysiological somatosensory evoked potentials. DSL – dissociative sensory loss, DS – deep sensibility, N13 – wave N13 after stimulation of median nerve, CP – conducted potentials after stimulation of tibial nerve, A – absent, PA – partially absent, L – left, R – right.*

Razpr. 1. *Klinični podatki o bolnikih, nevrološki izpadi senzoričnega sistema in značilnosti elektrofizioloških elementov intraoperativnih somatosenzoričnih evociranih potencialov. DS – disociacija senzibilitete, GS – globoka senzibiliteta, N13 – val N13 po stimulaciji medianega živca, PP – prevodni potencial po stimulaciji tibialnega živca, O – odsoten, DO – delno odsoten, L – levo, D – desno.*

Case Primer	Gender Spol	Age (years) Starost	Clinical problems Klinični problemi	DS	GS	N13 (side/stran) L/L	R/D	PP (side/stran) L/L	R/D
1	M	60	Avulsion of brachial plexus	no	no	normal		normal	
	M		Avulzija ramenskega pleteža	ne	ne	normalno		normalno	
2	F	32	Postherpetic pain of left arm	no	no	normal		normal	
	Ž		Poherpetična bolečina leve roke	ne	ne	normalno		normalno	
3	M	68	Reflex symphatetic dystrophy of right hand	no	no	normal		normal	
	M		Refleksna simpatična distrofija desne roke	ne	ne	normalno		normalno	
4	F	27	Avulsion of brachial plexus right	no	no	normal		normal	
	Ž		Avulzija ramenskega pleteža desno	ne	ne	normalno		normalno	
5	M	37	Avulsion of brachial plexus left	no	no	normal		normal	
	M		Avulzija ramenskega pleteža levo	ne	ne	normalno		normalno	
6	F	54	Syringomyelia C2–T2	yes	no	PA	A	normal	
	Ž		Siringomielija C2-T2	da	ne	DO	O	normalno	
7	M	41	Syringomyelia C1-C7	yes	no	A	A	normal	
	M		Siringomielija C1-C7	da	ne	O	O	normalno	
8	M	22	Syringomyelia C1-C7	yes	no	A	PA	normal	
	M		Siringomielija C1-C7	da	ne	O	DO	normalno	
9	F	38	Syringomyelia C1-C5	yes	no	O	O	normal	
	Ž		Siringomielija C1-C5	da	ne	O	O	normalno	
10	M	34	Syringomyelia C1-C3, C7-T1	yes	no	A	PA	PA	PA
	M		Siringomielija C1-C3, C7-T1	da	ne	O	DO	DO	DO
11	F	20	Syringomyelia C2-T1	yes	no	A	PA	normal	
	Ž		Siringomielija C2-T1	da	ne	O	DO	normalno	
12	F	39	Ependymoma C5-C6, Neurofibromatose Type 2	yes	no	PA	PA	normal	
	Ž		Ependimom C5-C6, Nevrofibromatoza tip 2	da	ne	DO	DO	normalno	
13	F	37	Ependymoma C5-C6	no	yes	A	PA	PA	PA
	Ž		Ependimom C5-C6	ne	da	O	DO	DO	DO
14	M	20	Ependymoma C3-C4	yes	yes	A	A	A	PA
	M		Ependimom C3-C4	da	da	O	O	O	DO
15	M	63	Ependymoma C5-C7	yes	yes	A	A	PA	PA
	M		Ependimom C5-C7	da	da	O	O	DO	DO
16	M	57	Ependymoma C5-T1	yes	yes	A	A	A	A
	M		Ependimom C5-T1	da	da	O	O	O	O

perature senses. Fast negative waves could be clearly identified in all patients' median nerve SEP and were most prominent in the blank N13 area. They were especially prominent in the cases with a sharp high amplitude negative wave. There the initial high amplitude negative wave was followed by a well-formed group of fast negative waves in which the potential ended. In cases with all four senses affected it sometimes occurred that no response at all could be elicited. The mean duration of median nerve SEP in patients was 8.81 ± 2.08 ms (n = 11) and was significantly shorter than that of normal median nerve SEP ($p < 0.0005$). It was significantly shorter in cases with additional loss of vibration and posture senses ($p = 0.001$; mean duration 7.17 ± 2.32 ms, n = 4) as well as in those in which only pain and temperature senses was found to be diminished or lost ($p = 0.0005$; mean duration 9.74 ± 1.30 ms, n = 7).

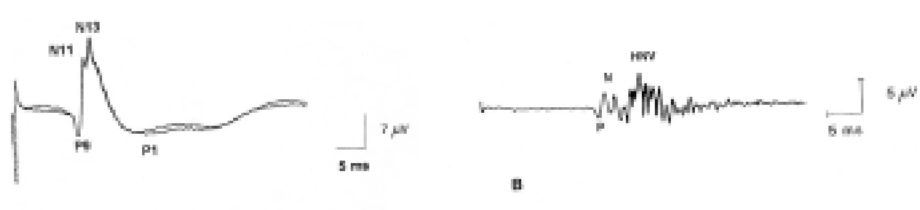

Figure 2. A. *Normal triphasic SEP response after median nerve stimulation recorded on the dorsal surface of C5 spinal cord segment. P9 – first positive wave with latency of 9 ms, N11 – negative wave with latency of 11 ms, N13 – negative wave with latency of 13 ms. In the normal SEP the fast negative waves (HNV) are almost not visible. B. Normal spindle shape SEP response after tibial nerve stimulation recorded on the dorsal surface of the C5 spinal cord segment. The most prominent are fast negative waves.*
P – first positive wave, N – negative waves at beginning, HNV – fast negative waves.

Sl. 2. A. *Normalni trifazni odziv po stimulaciji medianega živca, registriran na zadnji površini hrbtenjače v segmentu C5. P9 – začetni pozitivni val, N11 – negativni val z latenco 11 ms, N13 – negativni val z latenco 13 ms. HNV so v normalnem odzivu komaj zaznavni. B. Normalni vretenast odziv po stimulaciji tibialnih živcev, registriran na površini hrbtenjače v segmentu C5. Najizrazitejši so HNV.*
P – začetni pozitivni odklon, N – začetni negativni val, HNV – hitri negativni valovi.

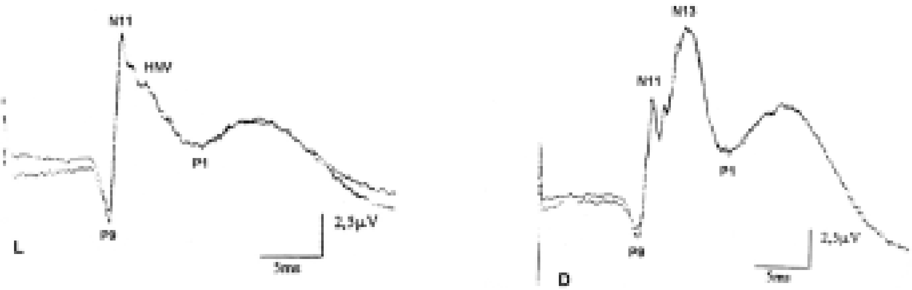

Figure 3. *SEP response after stimulation of median nerve recorded at C6 spinal cord segment in the patient with C5 C6 intramedullary ependymoma. Normal SEP on the right side. N13 wave is absent on the left side and fast negative waves (HNV) replace it. Presynaptic N11 is preserved. The patient has partial pain and temperature deficit on the left upper extremity. L – left, D – right.*

Sl. 3. *Somatosenzorični odziv po stimulaciji medianega živca, registriran v segmentu C6 pri bolniku z intramedularnim ependimomom v segmentih C5 C6. Na desni strani je normalen odziv. Na levi strani je val N13 odsoten in namesto njega se pojavijo HNV. Ohranjen je presinaptični val N11. Bolnik je imel delni izpad občutka za bolečino in temperaturo na levem zgornjem udu. L – levo, D – desno.*

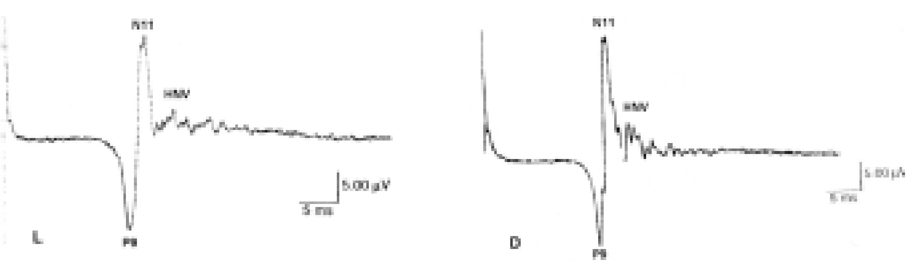

Figure 4. *SEP response after median nerve stimulation recorded at C6 spinal cord segment in patients with cervical syringomyelia. The patient has dissociative sensory loss in both upper extremities. Presynaptic wave N11 is preserved, N13 is lost and replaced by prominent fast negative waves (HNV). L – left, D – right.*

Sl. 4. *Somatosenzorični odziv po stimulaciji medianega živca, registriran v segmentu C6 pri bolniku s siringomielijo vratne hrbtenjače. Bolnik je imel disociacijo senzibilitete na zgornjih udih. Ohranjen je presinaptični val N11, val N13 pa je odsoten na obeh straneh in namesto njega so izraziti HNV. L – levo, D – desno.*

Normal conducted SEP following tibial nerve stimulation is presented in Figure 2B. Configuration of tibial nerve SEP in patients differed from normal (Figure 5). The most consisted waves were the initial negative waves. They could be observed in all recordings except in one case with complete sensory loss where no response at all could be obtained. In patients fast negative waves following the initial negative waves were fewer in number as compared to normal conducted SEP. These waves were all of approximately the same amplitude throughout the potential. This was usually lower than the amplitude of the initial negative waves and no spindle shape of tibial nerve SEP could therefore be observed. In cases with loss of vibration and posture senses in addition to those of pain and temperature we obtained partial loss of fast negative waves. In some cases fast negative waves were completely absent. Loss of these waves was in association with diminution or loss of vibration and posture senses. The mean duration of patients conducted SEP following tibial nerve stimulation was 13.52 ± 1.78 ms (n = 5) and was shorter than normal (p = 0.064).

Discussion

Triphasic high amplitude potentials obtained in our median nerve SEP were similar to those previously published in reports on median nerve SEP (9–12). Postsynaptic activity of DH interneurons is represented by large negative N13 (10, 13, 14). It is preceded by positive deflection P9, which is probably a far-field potential reflecting the afferent volley in brachial plexus. Triphasic potential consists also of positivity P1.

The most prominent feature of patient median nerve SEP was partial or complete disappearance of N13. It can be attributed to the damage of spinal cord gray matter by intramedullary located lesion in our patients. The results of our previous study (15) and also this study showed numerous fast negative waves on slow triphasic potential. It

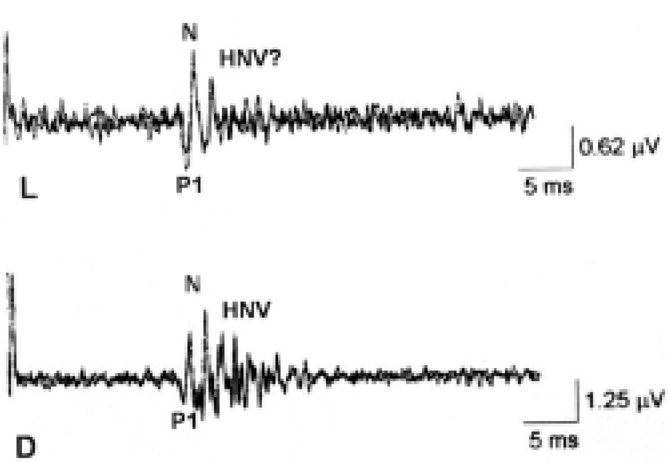

Figure 5. *SEP response after tibial nerve stimulation recorded at C5 spinal cord segment in the patient with C5 C6 intramedullary ependymoma. The vibration and joint position senses were lost in the lower extremities. Fast negative waves (HNV) have low amplitude, are distorted and partially lost. L – left, D – right.*

Sl. 5. *Somatosenzorični odziv po stimulaciji tibialnih živcev, registriran v višini C5 pri bolniku z ependimomom v višini C5 C6. Bolnik je imel senzorični izpad občutkov za vibracije in položaj sklepov na spodnjih udih. HNV imajo nizko amplitudo, so slabo oblikovani in delno odsotni. L – levo, D – desno.*

was also noticed these waves could be even better visible on the blank N13 area of our patients median nerve SEP. Obviously postsynaptic N13 can affect the visibility of synchronous fast negative waves. Our previous studies showed that cuneate fascicle might be the most important generator of fast negative waves on median nerve SEP (19). Single sharp high amplitude negative wave was found instead of wave N13 in some of our cases. This could be a remnant of N13 or a presynaptically generated event similar to what Austin and McCouch (16) described as N1a intramedullary spike. Our assumption that cuneate fascicle is the generator of fast negative waves is indirectly described by others. Many authors discussed an early fast negative peak N11 on the ascending slope of major negativity N13 (13, 17, 18). Jeanmonod and Sindou (4) noted a succession of such small sharp negative peak on ascending slope of a large negative slow wave N13. The number of these waves, considered to be N11, was greatest with dorsal funiculus recording, but more than one such wave could also be observed with dorsolateral or ventral funiculus recording. Berić et al. (11) described three to five additional low amplitude high frequency negative waves superimposed on large three-phase potential.

The destruction of DH by intramedullary lesion such as syringomyelia or tumor leads to partial or complete loss of N13 (7, 15, 19–23). The loss of spinal N13 was found to correlate with decrease in pain and temperature senses (24) but not those in touch, vibration or posture, what was confirmed with our results. In some of our cases with pain and temperature senses affected and with loss of N13, fast negative waves could not be distinguished from normal (19). Such cases were not seen with the loss of vibration and posture senses in addition to those of pain and temperature in which fast negative waves were always distorted. In patients with seemingly normal fast negative waves, the intramedullary lesion damaged the cervical spinal cord gray matter, reflecting in the loss of N13 and senses of pain and temperature. As seen from the apparently normal fast negative waves, the bulk of the generator of these waves was left intact, as were the senses of vibration and posture. This points towards the cuneate fascicle of DC as the most important generator of fast negative waves (19), located at the periphery of the cervical spinal cord. In cases in which loss of vibration and posture senses was found in addition to loss of pain and temperature senses, fast negative waves were the most severely distorted and had on average the shortest duration. Such cases were not found with only temperature and pain senses affected. The loss of N13 can be one-sided which suggests that the generators of N13 are different for each side stimulated. With one-sided loss of N13, the destruction must have involved only the DH gray matter on the side stimulated. Clinical examination usually reveals only a mild dissociate sensory deficit. If both-sided loss of N13 occurs the destruction of gray matter is so extensive that both DH are involved. It is usually accompanied by complete loss of pain and temperature senses (7, 21).

Tibial nerve SEP's were described by many authors (10, 25–27). The most consisted waves in our study were the initial negative waves representing activity of dorsal spinocerebellar tract (25). Therefore it seems that this tract is more resistant to intramedullary tumors or syrinx, because it is positioned at the periphery of the spinal cord. The leading element in tibial nerve SEP's are fast negative waves representing activity of the DC (11, 25, 28, 29). It was previously found that the disappearance of SEP following tibial nerve stimulation was associated with DC sensory deficit (19, 25). Damage to this structure resulted in loss or distortion of fast negative waves in our cases. The former is usually accompanied by complete loss of vibration and posture senses while with the latter these are just diminished. This points clearly to the DC dysfunction and more precisely to the gracilis fascicle.

Though diagnosis of intramedullary tumors relies exclusively on neuroimaging techniques (Figure 1A, 1B), MRI does not provide any information on spinal cord function in the region where the lesion is positioned. Myelotomies are connected with postoperative damage to the long sensory tracts or central gray matter, and therefore with postoperative neurological deficit (1, 2, 30, 31). Intraoperative findings with the help of SEP can be used for the purpose of prevention of possible postoperative sensory deficit (1, 30, 32). Functional anatomic information obtained with intraoperative SEP is of great help in planning the surgical approach to the spinal cord, i. e. either dorsomedialy between the gracilis fascicles or in the region of DREZ.

Changes of the elements of median nerve SEP and tibial nerve SEP are indicator of functional anatomy of the spinal cord during the operation. On the basis of our results we concluded that intraoperative SEP can be used to detect functional damage to DC fibers and DH neurons in intramedullary tumors and syringomyelia. The intraoperative SEP provide functional anatomic information, which a neurosurgeon can use for planning the microsurgical procedures on the spinal

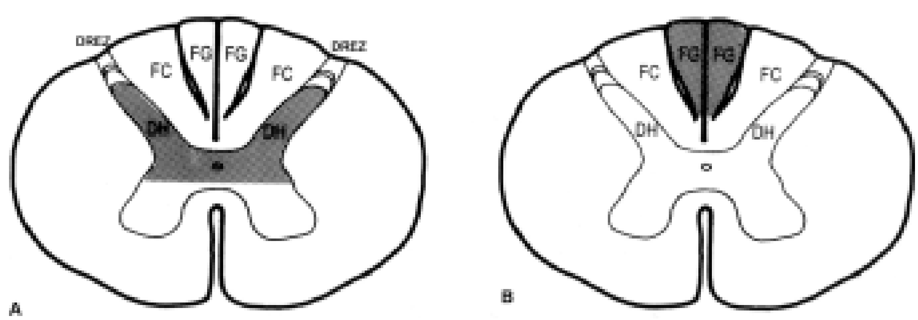

Figure 6. *Functional anatomic information composed from the clinical status of sensory functions and intraoperative SEP are of great help in planning the myelotomies. A. Dissociative sensory loss and N13 loss are characteristic for central cord damage. The microsurgical approach of choice is dorsolateral DREZ myelotomy. B. The loss of vibration and joint position sense and loss or distortion of fast negative waves (HNV) is the consequence of dorsal columns damage. The microsurgical approach of choice is dorsomedial myelotomy inbetween the gracilis fascicles. FG – fasciculus gracilis, FC – fasciculus cuneatus, DH – dorsal horn, DREZ – dorsal root entry zone.*

Sl. 6. *Funkcionalno anatomske informacije, sestavljene iz podatkov klinične preiskave senzoričnih dejavnosti živčevja in intraoperativnih SEP, pomagajo pri izbiri mielotomije. A. Pri bolnikih z disociacijo senzibilitete odsotnost vala N13 kaže na okvaro centralnih delov hrbtenjače. Boljši operativni pristop je dorzolateralna mielotomija skozi DREZ (dorsal root entry zone) področje in zadnji rog hrbtenjače. B. Bolniki z motnjo občutka za vibracije in položaj sklepov imajo odsotne HNV, kar kaže na okvaro zadnjih stebričkov hrbtenjače. Operativna metoda izbora v teh primerih je dorzomedialna mielotomija skozi žleb med gracilnima svežnjema. FG – fascikulus gracilis, FC – fasciculus cuneatus, DH – zadnji rog hrbtenjače, DREZ – dorsal root entry zone (področje vstopa zadnjih korenin).*

cord. In the cases with pain and temperature senses absent as in cervical syringomyelia patients we founded complete loss of N13 wave. Bilateral loss of the N13 suggests severe bilateral damage to DH gray matter. These data leads us to make the right decision about the approach to the syrinx lesion with the help of myelotomy. We believe that DREZ approach between the cervical roots would be better than dorsomedian approach since DC function is intact. The cases with unilateral loss of N13 as was the case of ependymoma suggest confinement of the lesion preferentially to one DH, and would prefer dorsolateral DREZ approach to the intramedullary tumor. In the cases in which vibration and posture senses are distorted or lost the fast negative waves of tibial and median nerve SEP are partially or completely lost. This suggest lesion to the gracilis or cuneate fascicle of the DC. Clearly the preferential plan for the operation of an intramedullary lesion would be dorsomedian approach between DC of the spinal cord. On the basis of our results we are convinced that complete or partial loss of N13 suggest damage to DH gray matter on the side of stimulation, and that loss or distortion of fast negative waves of tibial and median nerve SEP suggest damage to DC on the side of stimulation. The microneurosurgical approach which has advantage in the former situation is dorsolateral DREZ approach (Figure 6A), and in the latter situation dorsomedian between DC of the spinal cord (Figure 6B). The correlation between the clinical neurologic deficit of sensory functions, the changes of the elements of the intraoperative tibial nerve SEP and median nerve SEP and anatomic location of the lesion in the spinal cord gives us the functional anatomic information. These data are very helpful for planning the myelotomy in cases of intramedullary tumors and syringomyelia.

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