H Wave and Spinal Root Potentials in Neuromonitoring of S1 Root Function during Evacuation of Herniated Disc: Preliminary Results

Matej Makovec[1], Mitja Benedičič[2], Roman Bošnjak[2]

[1]Department of Surgery, General Hospital, Novo mesto, Slovenia

[2]Department of Neurosurgery, University Medical Center, Ljubljana, Slovenia

> **Correspondence to:**

Roman Bošnjak
Department of Neurosurgery
University Medical Center
Zaloška 7
1000 Ljubljana, Slovenia
Roman.Bosnjak@kclj.si

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Aim To determine the changes in the tibial H reflex and spinal nerve root potentials (SRPs) of the S1 root during posterior discectomy and the effects of surgical manipulation.

Methods Tibial H reflex responses (M and H waves) were intermittently recorded from the soleus muscle by surface electrodes during different stages of surgery in 5 patients with S_1 radiculopathy. All patients had Achilles reflex preserved bilateraly and no paresis on manual strength testing preoperatively. SRPs were additionally obtained by direct epidural recordings from the surgically exposed S_1 root in 2 of them.

Results The variations in the amplitude of H wave were minor and reversible upon the cessation of surgical manipulation of the root, but the H reflex was not lost either temporarily or permanently in any of the patients. Prolongation of H wave latency by up to 18% at the end of surgery in comparison with preoperative value was noticed in 4 patients. However, there was increased degree of desynchronization of the SRP in some phases of the spinal root manipulation, such as root mobilization before the disc incision and retraction during the disc evacuation. H waves and SRPs were continuously present during the surgery. Ankle jerks were preserved postoperatively in all 5 patients.

Conclusion Unremarkable variations in H wave latency may be followed by increased SRP desynchronization. Monitoring of the epidurally recorded SRPs seems to be more sensitive to surgical manipulations of the spinal nerve root than the tibial H reflex recordings from the soleus muscle.

Surgical manipulation of the lumbosacral nerve root is an inevitable step in posterior discectomy. Monosynaptic H reflex can be used in neuromonitoring of the S1 root function during evacuation of the herniated disc at the level L5-S1 to assess the extent of surgical manipulation. A subpopulation of patients with S1-root compression by herniated disc has a preserved ankle jerk at the time of surgery. The effect of surgical manipulations on the H wave amplitude and latency can be monitored during the surgery for herniated disc removal in such patients.

The H reflex plays an important role in the electrodiagnostic work-up of compressive lumbosacral radiculopathies, but it does not always give specific information even in clinical S_1-radiculopathy. Needle recording electrodes may be placed percutaneously under a fluoroscopic view as close as possible to each of the L_4-S_1 roots to identify exactly the abnormal spinal nerve root potential (SRP) of the compressed root upon tibial H reflex (1,2).

The H reflex has already been used intraoperatively as a neurophysiological test for the identification of certain roots or rootlets to increase the selectivity of partial dorsal rhyzotomy in spastic patients (3-5). However, continuous assessment of the S_1 spinal nerve root function by H reflex during discectomy has not yet been studied. In the present study, the H reflex and spinal root potentials (SRP) were during posterior discectomy to assess the effects of surgical manipulation.

Patients and methods

Patients

The data were collected from 5 patients with L_5-S_1 disc herniation and mild S1 radiculopathy (Table 1). Persistence of radicular pain was longer than 6 months and conservative treatment was attempted unsuccessfully for at least 3 months. Patients had normal or near-normal muscle strength of ankle plantar flexion and dorsiflexion upon manual testing, equal to the grade M5 or M4+ on the British Medical Research Council scale (6). Fatigability of the plantar flexor in patients was additionally tested by repetitive rising up onto the toes while standing on one leg (10×) and recorded as normal or abnormal (increased). The ankle jerk was present bilaterally. Sensory disturbance was recorded as present or absent. Root compression by dorsolateral herniated disc was confirmed by myelography and computed tomography or magnetic resonance imaging (MRI) in all patients. Patients with leg hypotrophy, chronic radiculopathy, bilateral radiculopathy, previous lumbar surgery, neuromuscular disorder, systemic disease, or polyneuropathy were not included in this study. Preoperative electrophysiological tests included nerve conduction studies, needle electromyography, and reflex studies.

All patients gave their informed consent. The procedure was approved by the National Ethics Committee of Slovenia (ref. No. 58/05/01).

Surgical technique

Microfenestration was the chosen surgical approach in all patients. The operative procedure was divided into 3 main stages as follows: root exposition, root manipulation, and wound closure. The patient was positioned prone with hip flexion of approximately 110° and knee flexion of 110°. The skin incision was made in the midline centered over the interspace L_5-S_1. The lum-

Table 1. Clinical and electrophysiological findings in 5 women patients with mild unilateral S_1 radiculopathy

Patient No.	Age (y)	Side	Sensory disturbance	Fatigability of affected plantar flexor muscles*	Manual strength testing		Ankle jerk	H wave latency (ms) on side	
					dorsi-flexion	plantar-flexion		affected	healthy
1	41	R	yes	abnormal	5	5	symmetrical	30.9	30.8
2	41	R	yes	abnormal	5	5	symmetrical	33.1	32.7
3	30	R	yes	abnormal	5	5	symmetrical	34.1	–
4	44	L	yes	abnormal	-5	5	symmetrical	29.7	29.9
5	41	L	yes	abnormal	5	5	symmetrical	31.2	30.8

*Abnormal fatigability of plantar flexion muscles was tested by repetitive (10x) rising up onto the toes of one leg.

bodorsal fascia was divided unilaterally. The paraspinous musculature was unilaterally stripped away from spinous processes and laminas L_5-S_1 subperiosteally. A portion of hemilamina and the ligamentum flavum was thus exposed and then the microscope was introduced. The ligamentum flavum was cut with a No.15 blade to enter epidural space. Partial hemilaminectomy, ie, fenestration, above and below the interspace was performed. Once the fenestration was created and the dural sleeve of the nerve exposed, two epidural electrodes were placed rostral and caudal to the discus hernia and the point of nerve root traction. The root was not manipulated during this stage of surgery. During the root manipulation stage of surgery, the root was first mobilized by a dissector. Mobilization of the root medially or laterally is a precondition to displace root to access the disc and intervertebral space below the root. The Love retractor (Aesculap® FF 700 R, Tuttlingen, Germany) was used to gently retract the nerve root medially to expose the underlying disc. The extruded disc material was first removed from below the root. The anulus fibrosus was then incised and nucleotomy was performed by use of forceps and spoon curette. The intermittent traction of the spinal root with the Love retractor was made during the entire evacuation of disc material. The retraction of the root was released each time when surgeon was passing the material to the scrub nurse (dynamic root retraction).

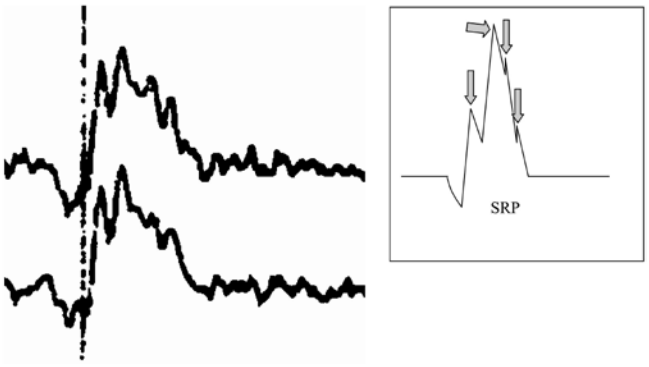

Figure 1. Desynchronization grade of the spinal root potential (SRP) is defined as a number of negative spikes of SRP (figure on the right; arrows). The surgical manipulation during evacuation of the disc affects the root between the proximal and distal electrodes and results in conduction dysfunction of the axons. The p2 potential of the SRP becomes desynchronized (figure on the left) when traveling distally past the manipulated area of the root.

The latency and amplitude of the H wave and spinal root potentials (SRPs) were recorded simultaneously. The manipulative stage was further divided on subsequent phases depending on spinal root manipulation. For wound closure, a drain was inserted and the fascia and skin were closed in layers.

Intraoperative neurophysiological examination

The H wave was elicited by intermittent percutaneous stimulation of the posterior tibial nerve at the popliteal fossa with an interelectrode distance of 2 cm. The cathode was positioned proximally to the anode. The constant-current stimuli were of rectangular shape, 1 millisecond in duration, and the intensity of stimulation of the tibial nerve was the threshold intensity for the M-wave in the calf muscles. At this intensity the H wave has the highest amplitude (1,2).

The M and H waves were recorded from the soleus muscle. A pair of platinum oval surface electrodes (2r = 2cm; Pals®, Model 896230) were placed along the midline of the calf muscle with the active electrode 1 cm distal to the insertion of the gastrocnemius muscle and the reference electrode 3 cm further distally.

Two bare-tip platinum wire electrodes (PISCES-Sigma, Generation II Lead Kit, Model 3483, Medtronic, Minneapolis, MN, USA) were placed epidurally for direct SRP recordings: one proximally at the axilla of the dural sleeve, and the other one distally at the entrance of the dural sleeve into the intervertebral foramen. The reference electrode was a needle inserted into the periosteum of the adjacent spinous process.

The latency and amplitude of the H wave were measured in all 5 patients, whereas desynchronization of SRPs was measured in 2 of them. After the H wave amplitude and latency were shown stable in the first 3 patients, we decided to perform SRPs in the remaining 2 patients, expect-

ing it to be a more sensitive method. The grade of desynchronization (1) was defined as a number of negative peaks of SRP wave (Figure 1).

Recording electrodes for SRP and compound muscle action potential (CMAP) were connected to a computerized modular electromyographic detection unit (Neuropack Four mini, Model MEB-5304K, Nihon Kohden, Tokyo, Japan; 4 channels, frequency band 5Hz-5kHz). Routinely, 2-3 responses of SRP were averaged. Latencies as well as amplitudes of the muscle evoked potentials were measured intermittently in each surgical stage at least in the beginning and the end of the procedure.

Anesthesia

The total intravenous anesthesia was induced with propofol (8-10 mg/kg/h) and fentanyl (1-3 g/kg/h), applied in an intravenous drip infusion. A single bolus of the short-lived muscle relaxant vecuronium (half-time of 15-minute) was given to ease endotracheal intubation. The skin incision was performed at least 30 minutes after the anesthetic induction.

Results

The variations in the amplitude of H wave were minor and reversible, but the H reflex was not lost either temporarily or permanently in any of the patients (Figure 2). The changes in latency were not significant. The largest prolongation of latency in our patients was only up to 18% of the initial value. The most discrete sign of cumulative manipulative effect was slightly and temporarily increased stimulus threshold for H wave. In all cases, the ankle jerk was preserved postoperatively with no additional motor deficit.

The SRP was found to be composed from two waves – p1 (afferent volley) and p2 (efferent volley). The p1 and p2 detected with the distal electrode in the intervertebral foramen were signed as $p1_{distal}$ and $p2_{distal}$. The characteristics of $p2_{distal}$ and $p2_{proximal}$ were analyzed as the efferent volley transited the compressed and manipulated area of the root from proximal to distal direction.

The $p2_{distal}$ was more desynchronized than $p2_{proximal}$. The manipulation of the spinal root resulted in additional increase in the grade of desynchronization of $p2_{distal}$ compared with $p2_{proximal}$ in the phases of root mobilization and root retraction (Figures 3 and 4). The difference between the degree of desynchronization in $p2_{distal}$ and $p2_{proximal}$ was presented by subtraction of the number of negative peaks proximally from

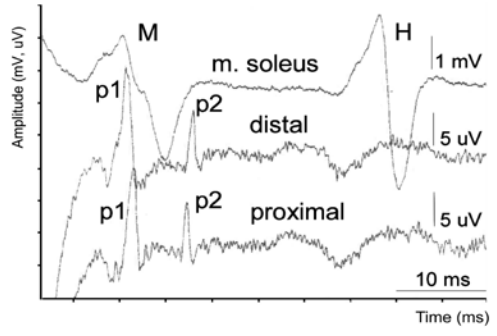

Figure 2. Typical M and H waves and spinal nerve root potentials (SRP) recorded during the removal of herniated disc in patient No. 2. SRP consisted of two peaks: the ascending volley p1 and the descending volley p2. Each epidural electrode (proximal and distal) detects p1 and p2 volleys of the H reflex.

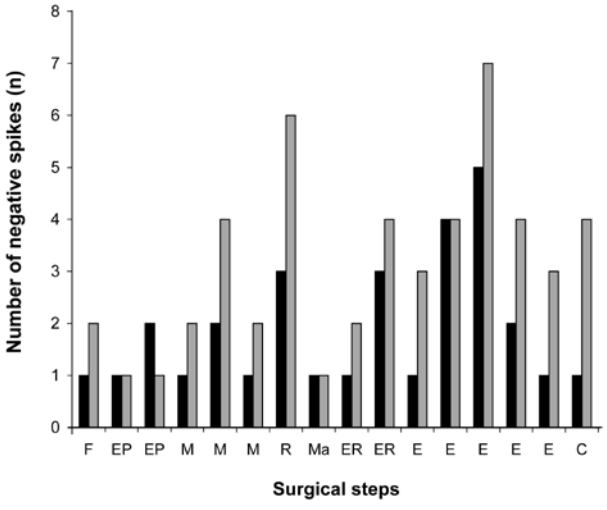

Figure 3. Patient No. 1. Number of negative spikes of p2 wave was increased during some stages of surgery when p2 was conducted from proximal (black area) to distal electrode (gray area). Note the higher grade of desynchronisation of p2 recorded distally (gray area) in almost all phases of manipulative stage, especially during root mobilization (M) and retraction during disc material evacuation (E). Surgical stages: F – fenestration, EP – placement of epidural electrodes, M – mobilization of the root by blunt dissector, R – introducing root retractor, Ma – unspecified manipulation with bipolar coagulation pincet, ER – reposition of the displaced electrodes, E – evacuation of the disc material, and C – wound closure.

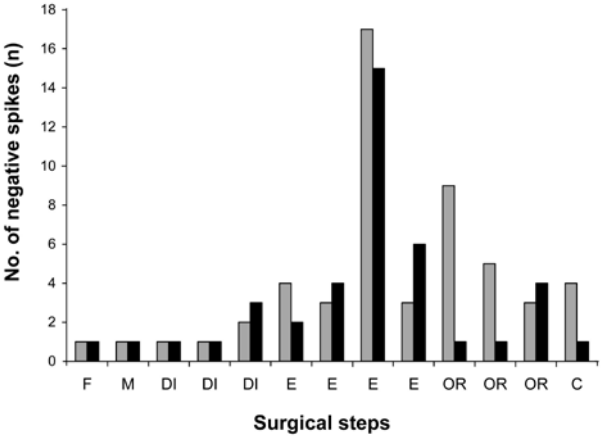

Figure 4. Patient No. 2. Number of negative spikes of p2 wave was increased in some stages of surgery when p2 was conducted from proximal (black area) to distal electrode (gray area). Desynchronization of p2 distally was increased during evacuation (E) of the disc material. Surgical stages: F – fenestration, M – mobilization of the root by blunt dissector, DI – incision into the disc, E – evacuation of the disc material, OR – removal of the osteophytes, and C – wound closure.

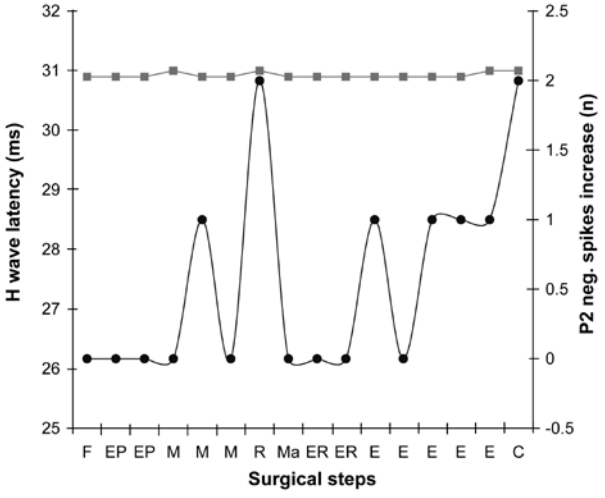

Figure 5. Patient No. 1. Variations in the latency of H reflex (upper curve) and grade of desynchronization of the SRP (lower curve) during different stages of surgery. The latency was relatively constant during whole surgery, but the grade of desynchronisation of the p2 wave follows the surgical manipulations more reliably. Surgical stages: F – fenestration, EP – placement of epidural electrodes, M – mobilization of the root by blunt dissector, R – introducing root retractor, Ma – unspecified manipulation with bipolar coagulation pincet, ER – reposition of the displaced electrodes, E – evacuation of the disc material, and C – wound closure.

number of negative peaks distally (Figures 5 and 6).

The latency of H wave remained constant in the patient No. 1 (Figure 5), but increased in a stepwise manner and remained increased in patients No. 2 (Figure 6) and No. 4, it returned to the original value after stepwise increase in the patient No. 3, and showed a stepwise increase after root mobilization in the patient No. 5.

The H wave amplitude remained almost constant in the patient No. 1, whereas in the patient No. 2 and 5, the amplitude decreased in some phases of manipulative stage and remained extremely low in the end of the procedure (data not shown). A preservation of the amplitude of the H wave at the end of surgery was related to the preservation of the H reflex after surgery.

Discussion

Monosynaptic H reflex may be used in neuromonitoring of the S_1 root function during the evacuation of herniated disc at the level L_5-S_1. Only a subpopulation of patients with S_1 root compression by herniated disc and preserved ankle jerks at the time of surgery are suitable candidates for this type of neuromonitoring.

Dynamic retraction technique of the root manipulation during evacuation of the herniated disc is supposed to decrease the total retraction load to the root and achieve better clinical results in most patients (7). However, the surgeon does not have an immediate feedback on when exactly the retraction is too strong or prolonged, or both, in a particular patient. We found that the latency of the H reflex was not a sensitive enough method to detect acute conduction abnormalities during this operative technique. The amplitude of the H reflex was found to be more sensitive for this purpose. We were able to reverse the amplitude drop by immediately stopping the root retraction. In each patient, we were able to preserve the H reflex during the whole surgery, which correlated with the preservation of ankle jerk. Reversibility of the amplitude of the evoked muscle potential after cessation of manipulation and its preservation at the end of surgery have been recently reported to correlate strongly with good neurological outcome also in neuromonitoring of other peripheral nerves (8).

We simultaneously studied H waves and epidurally recorded SRPs in two patients, No. 1 and 2. In the previous reports (1,2), the statistical analysis revealed a highly linear relationship between the amplitudes of SRP and H wave in both the rising and falling phases of the recruitment curve. In addition, the p2 of the SRP wave was never recorded in situations in which H reflexes were not evoked. Thus, the results confirmed that the SRP represents the α-efferent volley, which was reflexively activated resulting in the H reflex (1,2).

Patients No. 1 and No. 2 showed an increased grade of p2 desynchronization at the distal recording site before any root manipulation. The most likely explanation is the compressive effect of the herniated material on the spinal root conduction. Also, the distal recording electrode was probably positioned more closely to the compression site, which is thus closer to the root ganglia than to the axilla of the dural sleeve. Granger (9) and Malcolm (10) measured the speed of nerve conduction following stimulation within the theca of the cauda equina at the time of surgical removal of a compressive lesion. There was a decrease in the speed of the nerve-impulse past the compressed segment of the nerve root. A pressure magnitude of 30-50 mm Hg was reported in moderately large herniated discs (11).

The two patients in our study showed further increases in desynchronization grade after the manipulation of the spinal root in some stages of surgery. A cumulative effect of spinal root retraction on spinal root conduction is a possible explanation.

All patients except patient No. 1 showed steady prolongation of H wave latency. Kammer showed a significant effect of propofol in spinal motor responses (12). The latency of the H reflex increased and the amplitude decreased with increasing anesthetic concentration. Kerz observed H-reflex depression only at higher blood concentration (13). Although all patients received the same dose per kg per min of propofol, plasma concentration might be different. This may explain steady prolongation of H wave latency and decrement of the H wave amplitude in last 4 patients. The second possible reason is a steady cooling of the operative field. However, spinal root manipulation and consequently conduction slowing or blocking are responsible for the sudden but reversible decrements of H wave amplitude in some phases of the manipulative stage, where the amplitude recovered promptly after stopping the potentially harmful manipulations to the root. A need to increase the stimulus intensity to recover the amplitude was obtained before amplitude decrement (14). The alternative explanation of the increase in stimulation threshold for elicitation of H wave could be technical in some patients. The most subtile sign of root affection by repetitive or prolonged surgical manipulation seems to be the increase in number of negative spikes of p2 potentials (desynchronisation) detected with the proximal electrode in the intervertebral foramen.

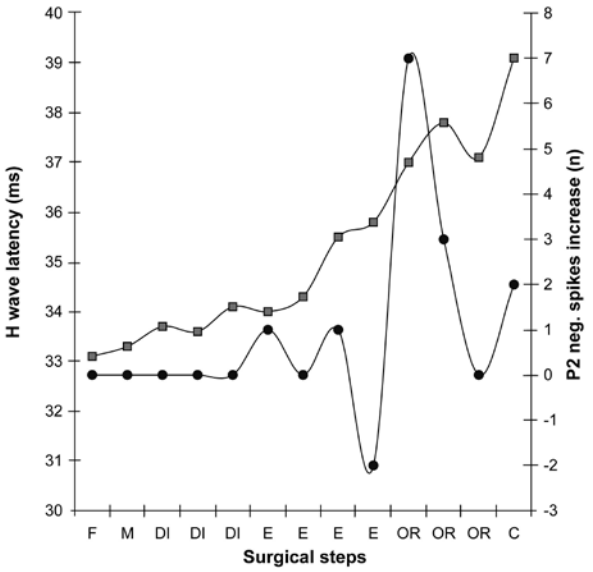

Figure 6. Patient 2. Variation in latency of H reflex (upper curve) and SRP desynchronization (lower curve) during different stages of surgery. The latency is steadily increasing during the whole stage, but the grade of desynchronisation of the p2 wave follows the surgical manipulations more sensitively. Surgical stages: F – fenestration, M – mobilization of the root by blunt dissector, DI – incision into the disc, E – evacuation of the disc material, OR – removal of the osteophytes, and C – wound closure.

The major limitation of our study design is relatively small and variable amplitude of the H wave as compared to M waves. Percutaneous stimulation of the peripheral nerve is concerned with a more variable amount of the electrically activated axons in the nerve trunk with each stimulus than direct (contact) nerve stimulation. The H waves can thus be evaluated only as present or absent. Bilateral measurements of conduction velocity of the H waves are necessary to follow the effects of anesthetics and room temperature.

In conclusion, tibial H reflex monitoring during S1 root decompression is a useful method to control surgical manipulative actions and to warn the surgeon of prolonged or forceful traction of the root. SRP monitoring brings up additional and the earliest information concerning initial root conduction dysfunction from cumulative manipulative effects. The technique of dynamic retraction can thus be further improved. It is unclear from our results obtained on only 5 patients if epidural recording of SRP, which is technically demanding, has a significant advantage over H wave amplitude recordings.

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