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Soleus H-reflex to S1 nerve root stimulation

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Abstract

H-reflexes in normals were elicited by percutaneous electrical and magnetic stimulation of proximal nerve roots at the cauda equina. H-M interval to S1 nerve root stimulation at the level of the S1 foramen was 6.8 ± 0.33 ms, with side to side difference of 0.16 ± 0.13 ms. Compression/ischemia of the sciatic nerve in the mid-thigh abolished the H-reflex to stimulation of the tibial nerve at the popliteal fossa when the H-reflex to S1 nerve root stimulation was preserved. The length of the S1 nerve root in human cadavers was measured to be 17.5 ± 03 cm, providing an estimated dorsal root conduction velocity of 67.3 m/s and a ventral root conduction velocity of 54 m/s. We conclude that the H-M interval to S1 root stimulation can provide reliable measures of conduction within the spinal canal including proximal afferents, anterior horn cells and ventral roots. © 1998 Elsevier Science Ireland Ltd.

Keywords: H-reflex; S1 root stimulation; H-M interval

1. Introduction

Recent studies have documented that soleus H-reflex can be elicited by magnetic or electrical stimulation of the S1 nerve root and proximal portions of the sciatic nerve (Zhu et al., 1992; Ertekin et al., 1996; Maccabee et al., 1996). The ability to elicit the soleus H-reflex from stimulation of several different sites (S1 nerve root, sciatic nerve, tibial nerve) will be of help in distinguishing between proximal and distal involvement of the reflex pathway. Traditional methods of testing soleus H-reflexes to stimulation of the tibial nerve are compromised by the relatively long segments of nerves that must be traversed to elicit the reflexes, and if only a small portion of the pathway is affected there will be a ‘dilution’ of the abnormality of conduction by the normal conduction of the remainder of the pathway (Eisen, 1991; Kimura et al., 1994). This study reports on measures of latency and amplitude of H-reflexes to S1 nerve root stimulation in a normal population and the effect of inducing a reversible proximal sciatic nerve lesion by ischemia on these measures. The conduction velocity of the S1 nerve root within the spinal canal was calculated using measures of the length of the S1 nerve root in 15 cadavers.

2. Materials and methods

We studied 60 normal subjects, 19–62 years, with their informed consent. The tests were performed bilaterally and included (1) soleus H-reflexes to both percutaneous electrical stimulation at the S1 foramen and to electrical stimulation of the tibial nerve at the popliteal fossa; (2) fifteen of these patients were tested unilaterally with magnetic stimulation of the S1 nerve root. Electrical stimulation of the tibial nerve employed 1 ms uniphasic pulses applied through 0.3 cm diameter electrodes. Electrical stimulation of the S1 nerve root was performed with a high voltage electrical stimulator, the Digitimer D180 (Digitimer Co. Ltd.), which produced a brief 0.1 ms capacitance discharge of approximately 300-750 V applied through 1 cm diameter electrodes. The cathode was placed on the skin overlying the S1 foramen and the anode on the abdomen at the same level. Magnetic stimulation was delivered with a Cadwell MES-10 magnetic stimulator (Cadwell Laboratories. Inc.). A 9.5 cm diameter circular coil was positioned tangentially to the skin with the edge over the S1 foramen. A rostrad

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current flow was used. For both the electrical and magnetic techniques, the stimulus was delivered every 10-20 s. The intensity used was adjusted to elicit the maximum amplitude of the H-reflex for that individual.

Compound muscle action potentials were recorded from soleus muscle with surface electrodes. The active electrode was placed over the medial bulge of soleus, below the gastrocnemius margin with the reference electrode 3 cm distal to the active electrode (Hugon, 1973). Baseline-to-peak amplitudes of the potentials were measured. Latency was measured at the peaks of the M and H waves for the S1 root stimulation since the onset of the H-reflex was often obscured by the preceding M wave. In 10 subjects with a clear onset of the H-reflex, the H-M interval measured to the peak of the major negative phase of the H and M waves showed no significant difference from that measured to the onset latency of the H-reflex and M wave. During tibial nerve stimulation, onset latencies of the H-reflex were defined.

Statistical measures of the significance of side to side differences in latency were assessed by Student's *t* tests with significance levels at the $P = 0.05$ level. Correlational coefficients between subject height and H-reflex latency were defined.

2.1. Ischemia

In two individuals, unilateral ischemia of the sciatic nerve was induced by a blood pressure cuff placed around the thigh 15 cm above the knee and inflated to a pressure of 300 mmHg for up to 20 min (Magladery et al., 1950).

2.2. Stimulation of the cauda equina

In 10 subjects, electrical stimulation at different levels of the cauda equina was tested unilaterally by placing the stimulating cathode electrode at (1) the S1 foramen (2) between the spinal processes of L5-S1 (3) L3-L4 and (4) T12-L1, with the anode positioned over the abdominal wall at levels corresponding to the position of the cathode.

2.3. Anatomical studies of S1 root

The length of the dorsal root of the S1 nerve within the spinal canal was defined in 15 cadavers (9 males, 6 females; height 162–192 cm, mean 172 cm). The specimens were dissected on one side to reveal the S1 nerve root. The length of the S1 root was measured between the distal end of the dorsal ganglion (where the dorsal root joins the ventral root to form the S1 nerve) and the entry point of the dorsal root into the spinal cord.

The conduction velocities of the dorsal root and the ventral root were calculated using measures of the length of the S1 nerve root and conduction time of the H-reflex within the spinal canal.

3. Results

Electrical or magnetic stimulation of S1 nerve root at the S1 foramen evoked in the soleus muscle two distinct potentials separated by approximately 7 ms. The initial potential is the M wave and the second potential is the H-reflex (Fig. 1). The threshold of the H-reflex was lower than that of the

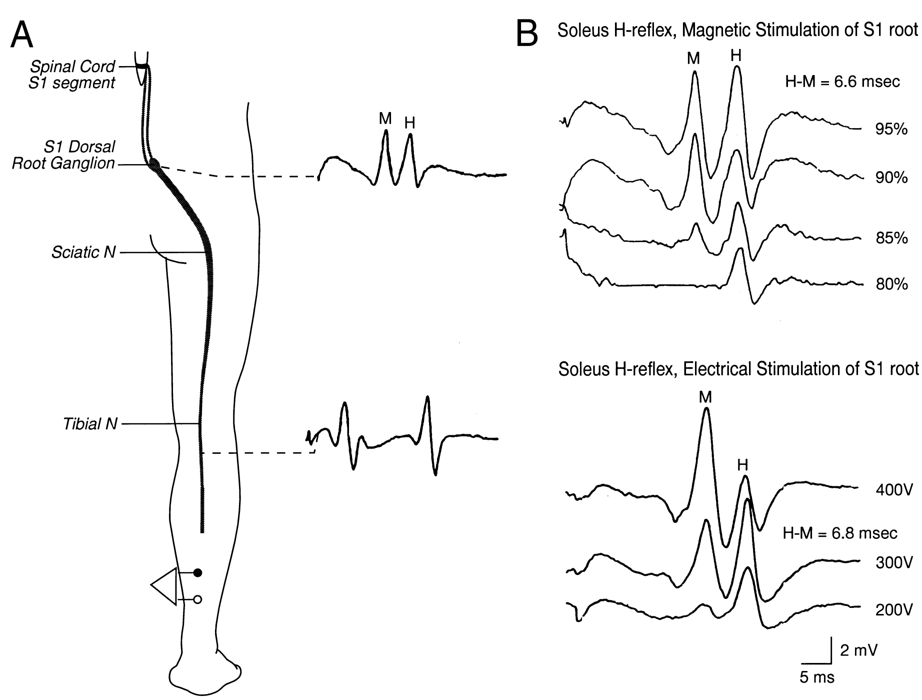

Fig. 1. (A) Schematic representation of soleus H-reflexes from electrical stimulation of the S1 nerve root at the S1 foramen and of the tibial nerve at the popliteal fossa. (B) The response complex of the H-reflex and M wave in one of the subjects elicited by magnetic (upper traces) and electrical stimulation (lower traces) of the S1 nerve root at the S1 foramen. The intensity of the nerve stimulus is to the right of the traces.

Table 1

Normal values for H-reflex

Number of subjects	60
Age range (years)	19–62 (mean 43)
Height range (cm)	155–190 (mean 169)
S1 root stimulation:	
H-M interval (ms)	6.8 (SD = 0.33)
Range of H-M interval (ms)	5.6–7.7 ms
Correlation H-M interval vs. height	$r = 0.54$ ($P < 0.01$)
Mean difference in H-M interval between two sides (ms)	0.16 (SD = 0.12)
Mean S1 H amplitude (mV)	1.9 (SD = 0.37)
Range of S1 H amplitude (mV)	0.9–3.0
Tibial nerve stimulation:	
Mean H-reflex latency (ms)	29.6 (SD = 2.21)
Range of H-reflex latency (ms)	26.4–34.0
Correlation H-reflex latency vs. height	$r = 0.89$ ($P < 0.01$)
Mean difference in H-reflex latency between two sides (ms)	0.49 (SD = 0.36)
Mean tibial H amplitude (mV)	5.2 (SD = 2.2)
Range of tibial H amplitude (mV)	1.8–11.0

M wave in all subjects. Increasing the stimulus intensity was accompanied by a progressive increase in the amplitude of both M and H responses and a subsequent decline in the H-reflex amplitude while the M wave continued to grow. Measures of the H and M potentials in the 60 subjects are presented in Table 1 along with the traditional measures of H-reflexes from tibial nerve stimulation. In 15 subjects tested with magnetic stimulation of the first sacral nerve root, there were no significant differences in the H-M intervals as compared to electrical stimulation of the sacral nerve root. Measures of the H-reflex to electrical stimulation of the S1 nerve root and to tibial nerve stimulation are included in Table 1.

The H-M interval to stimulation of the S1 nerve root varied only slightly in contrast to the traditional H-reflex latency derived from tibial nerve stimulation. The greater variability of the H-reflex latency to tibial nerve stimulation is related to subject height and the accompanying differences in the length of the reflex pathway traversing the leg. In contrast, the mean length of the S1 nerve root has a SD of only 0.3 cm in cadavers varying widely in height. The correlation between the latency of H-reflex and subject height accounted for a greater proportion of H-reflex variance with tibial nerve stimulation ($r = 0.89$) than with S1 root stimulation ($r = 0.54$). The side-to-side difference of the S1 H-M interval was less than the side-to-side difference of the tibial H-reflex. The amplitude of the H-reflex (Hmax) to S1 root stimulation is significantly smaller (approximately 1/3) than to tibial nerve stimulation, most likely reflecting differences in the nerve fiber population activated by the different pulse duration (1 ms for tibial nerve stimulation; 0.1 ms for S1 nerve root stimulation) used in the two methods (Panizza et al., 1989).

3.1. Ischemia

Fig. 2 contains the result from one subject during ischemia of the mid-thigh. Within 15 min the latency of both the M wave and H-reflex to tibial nerve stimulation lengthened by approximately 2 ms with an accompanying reduction of their amplitudes. By 20 min the H-reflex was lost. H-reflexes to S1 root stimulation were tested at the onset of the ischemia and again at 20 min when tibial H-reflex was absent. H-reflex was still present to S1 root stimulation with the H-M interval lengthening 0.2 ms, a value within the normal variability of this measure. The amplitude of the Hmax was reduced approximately 50%. In both of the subjects tested, a 20 min period of ischemia of the sciatic nerve abolished the tibial nerve H-reflex whereas the S1 H-reflex remained intact. This finding indicates how the use of both tibial nerve and S1 root stimuli for evoking H-reflexes can localize the site of nerve involvement.

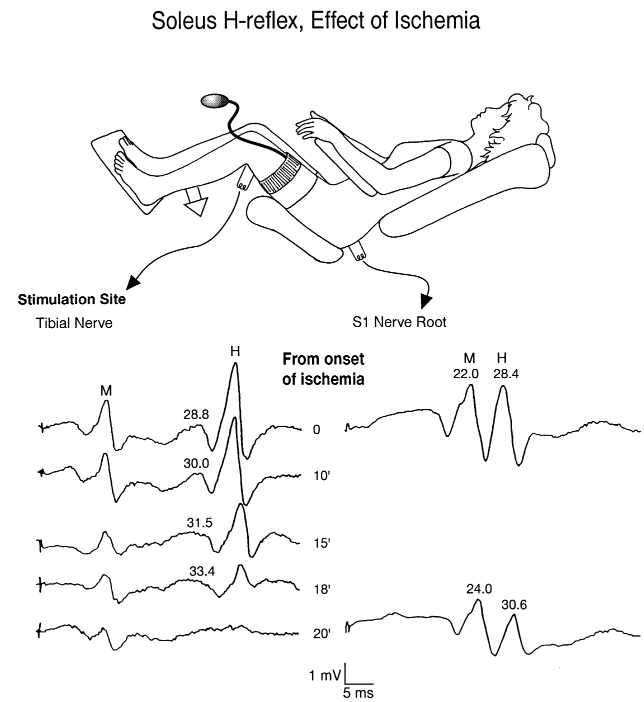

Fig. 2. Effect of compression/ischemia of sciatic nerve in the mid-thigh on H-reflexes in a healthy subject. After 20 min of ischemia the H-reflex elicited by tibial nerve stimulation is lost whereas it is preserved from S1 root stimulation. Measures of the H and M waves are listed above each of the traces.

Table 2

H-M interval from different stimulation sites

	Mean H-M interval
T11-T12	H and M cannot be distinguished
T12-L1	2.6 ± 0.7 ms
L2-L3	4.2 ± 0.6 ms
L4-L5	5.5 ± 0.3 ms
S1 foramen	6.8 ± 0.5 ms

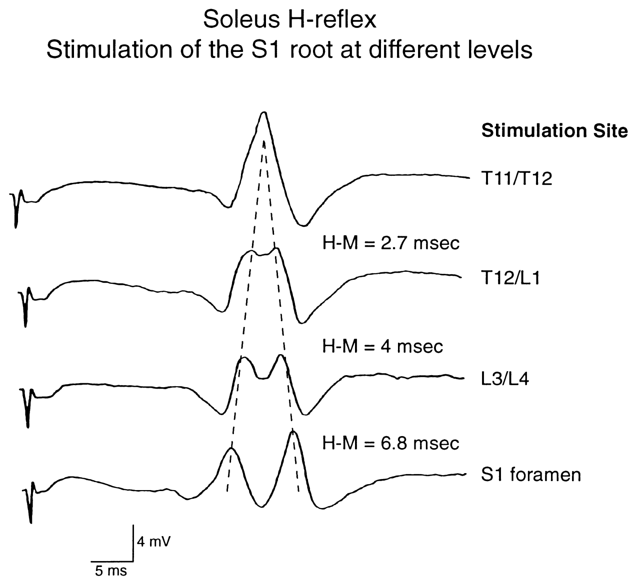

Fig. 3. H-reflex to electrical stimulation of the S1 root at different spinal levels. Note the progressive decrease of H-M interval as the site of stimulation moved rostrad. Also note that the H and M components are fused with stimulation at the T11-T12 site.

3.2. Stimulation of the cauda equina

Electrical stimulation of the S1 nerve root at different levels within the cauda equina evoked H-reflexes which differed in latency (Fig. 3). The H-M interval reduced progressively as the site of stimulation moved rostrad and amounted to approximately 4 ms between S1 foramen and the L1-T12 level (Table 2; Fig. 3). H-reflexes could not be distinguished from the M wave at the T11-T12 level compared to more caudal sites. The threshold for eliciting the H-reflex was lower than that for the M wave along the S1 nerve root in all subjects (Fig. 4).

3.3. Anatomical studies of S1 nerve root

The mean length of S1 nerve root was 17.5 ± 0.3 cm (range from 16.5 to 20.5 cm, Fig. 5). Assuming that these measures in cadavers are representative of the length of the S1 root before death and fixation, the conduction velocity of the S1 nerve root in vivo can be estimated. The mean H-M interval was 6.8 ms which includes one ms for monosynaptic activation of the motor neurons, leaving 5.8 ms as the travel time in the dorsal and ventral sacral roots. Our earlier data (Zhu et al., 1992) suggested that the conduction velocity of the Ia afferents was approximately 18% faster than motor efferents in the proximal segment of the sciatic nerve, giving the travel time of 2.6 ms and a motor efferent travel time of 3.2 ms. The travel time in each of the roots divided by the length of the root (8.75 cm) gives a Ia afferents conduction velocity of 67.3 m/s and a motor efferents conduction velocity of 54.7 ms (Table 3).

Table 3

The sensory fiber and motor nerve fiber conduction velocity in the S1 nerve root within the spinal canal

Length of S1 nerve root (cm)	17.5[a] (SD = 0.3)
H-M interval (ms)	6.8[b]
Synapse delay (ms)	1.0
Total conduction time in the S1 root (ms)	5.8
Conduction time in the afferent fiber (ms)	2.6
Conduction time in motor nerve (ms)	3.2
Conduction velocity (m/s)	67.3
Motor conduction velocity (m/s)	54.7

[a]Mean value from 15 cadavers.
[b]Mean value from 30 normal subjects.

4. Discussion

The results of this study provide normative data on soleus H-reflexes from stimulation of the S1 nerve root. The measures of latency were less affected by subject height than the latency of the H-reflex evoked by tibial nerve stimulation. Moreover, stimulation of the S1 nerve root allowed the detection of an H-reflex when it disappeared to tibial nerve stimulation following a temporary and partial conduction block of the sciatic nerve in mid-thigh. The H-M interval remained stable following the ischemia whereas H-

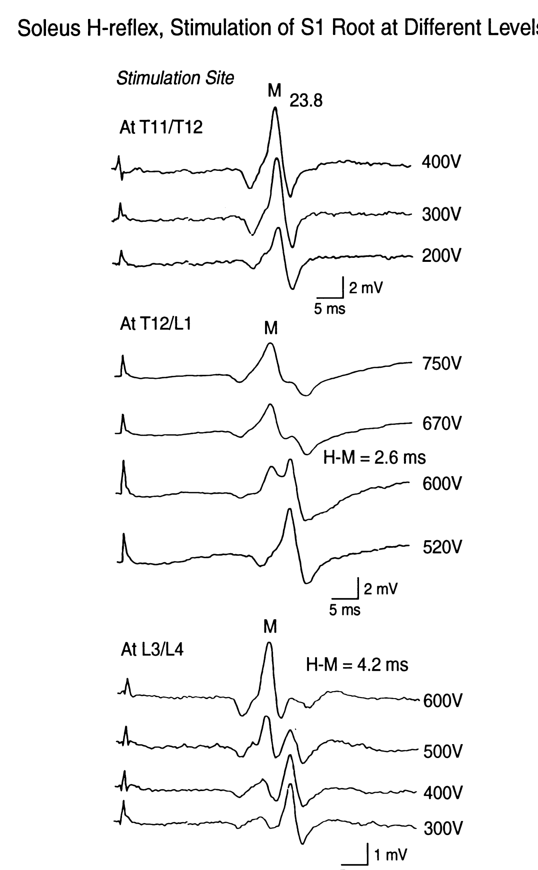

Fig. 4. H-reflex to electrical stimulation of the S1 nerve root at different spinal levels. The H-reflex has a lower threshold than the M wave at all test sites. At the T11 level the H-reflex cannot be defined. The intensity of the stimulus is to the right of the traces.

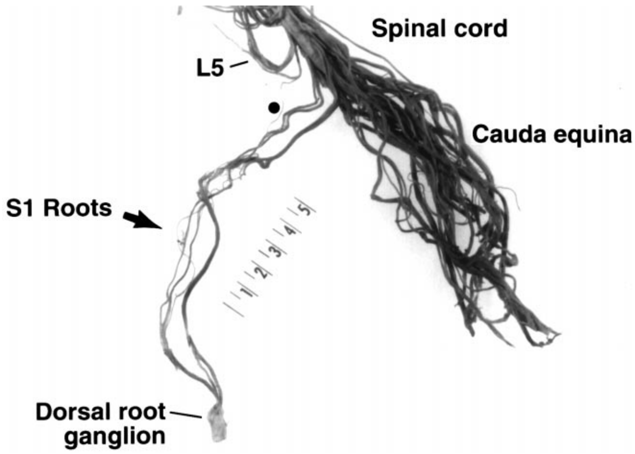

Fig. 5. Anatomical specimen of cauda equina from a cadaver showing the length of the S1 dorsal and ventral roots (large arrow) between the S1 root dorsal ganglion and the spinal cord. The S1 root in this specimen measured 17 cm. The L5 root has been retracted to facilitate the display. Note a fine neural branch (large dot) extending from the L5 root to the S1 root.

reflexes to tibial nerve stimulation lengthened out-of-proportion to the M wave changes during the ischemia. These findings complement earlier studies of the possible clinical feasibility of S1 nerve root stimulation for H-reflexes using magnetic (Zhu et al., 1992; Maccabee et al., 1996) and electrical stimulation (Ertekin et al., 1996). The application of S1 nerve root stimulation methods for eliciting H-reflexes provides a method for distinguishing between proximal and distal lesion sites of the S1 nerve root and its peripheral pathway subserving soleus H-reflexes. Moreover, the ability of eliciting soleus H-reflexes with different latencies from stimulation at different levels of the cauda equina could provide a means for localizing the site of abnormality to restricted portions of the S1 nerve root.

The combination in this study of anatomical measures of the length of the S1 nerve root with the physiological measures of the latency of the H-reflex to S1 nerve root stimulation allowed an estimate of the conduction velocity of the Ia afferents within the spinal canal. The resulting value of 67 m/s is similar to estimates provided by other methods (Mayer and Mawdsley, 1965; Panayiotopoulos et al., 1978).

A limitation of S1 nerve root stimulation is the discomfort that is experienced using high voltage percutaneous electrical stimulation. Magnetic stimulation avoids this degree of discomfort and can elicit soleus H-reflexes but only at the S1 foramen. The spread of current is too great using magnetic stimulation to localize the stimulus sites to more proximal portions of the S1 nerve root within the spinal canal.

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