Conduction velocity along human nociceptive reflex afferent nerve fibres

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SYNOPSIS The conduction velocity along the nociceptive flexor reflex afferent nerve fibres was investigated in human subjects. The posterior tibial nerve was stimulated at two sites by single painful electrical shocks of 1.0 ms duration and with adequate intensity and the reflex EMG discharges were recorded from the short head of the biceps femoris muscle. The fastest reflex conduction velocity along the posterior tibial nerve between the ankle and the popliteal fossa was about 10–25 m/s. Thus the fastest flexor reflex afferent fibres associated with a painful sensation were thought to be included in the A-delta group of cutaneous afferent nerve fibres.

Although human exteroceptive withdrawal reflexes have been investigated from many respects and are still being studied by different research groups, surprisingly little is known about the propagation velocity of the impulses along the nerve fibres involved. There are differences and conflicting views even about the type of fibres and their conductivity in the peripheral afferent limb of flexor reflexes. Some authors have stressed that the conduction velocity of the afferent side of the flexor reflexes is about 30–50 m/s particularly for the withdrawal reflexes of the lower limb (Pedersen, 1954; Hagbarth, 1960; Shahani, 1970; Shahani and Young, 1971). It has also been proposed that the maximal afferent conduction velocity of the reflexes could hardly be less than 50 m/s (Grimby, 1963). According to these reports, the fastest peripheral afferent impulses evoking reflex electromyographical discharges from the flexor muscles could be conducted to the spinal cord by the group II skin afferent nerve fibres of Lloyd (1943). On the other hand, a few authors have suggested that the maximal conduction velocity on the afferent side of the flexor reflex could be about 20–25 m/s which would indicate the group III skin afferents of Lloyd (1943), or, in another term, the small diameter myelinated A-delta fibres (Kugelberg, 1948; Dimitrijević and Nathan, 1970).

In this study, the conduction velocity of the nociceptive flexor reflex afferent nerves has been systematically investigated by applying painful electrical shocks to the posterior tibial nerve at two different sites and recording electromyographically from the ipsilateral biceps femoris muscle. It will be demonstrated that the reflexes producing evoked responses from the short head of the biceps femoris muscle are centrifugally conducted at an average speed of 10–25 m/s along the posterior tibial nerve and therefore nociceptive afferent nerve fibres in this reflex could be the A-delta fibres.

METHODS

Twenty-two normal healthy volunteers (one female, the others male, 17 to 47 years of age with a mean age of 28.5 years) were examined. In addition, 19 patients with the tentative diagnosis of sciatica who were submitted to the laboratory for EMG evaluation were included in the study. These cases were selected for absence of any objective sign of motor, sensory, and reflex involvement in the leg, having only the radicular pain as being characteristic of sciatica. Radiographs of the lumbosacral spine in these cases were not significantly pathological and their EMG examinations were also within normal limits; neither denervation potentials nor loss of motor units was encountered in the muscles corresponding to L 4/5 and S1 myotomes. Motor conduction velocities were
within the normal ranges of the posterior tibial and lateral popliteal nerves. Nevertheless, the patients were separated as a different group from the 22 normal volunteers. The sciatica group had a mean age of 38.3 years (range 20–67 years) and all of them were male.

Subjects lay supine on the firm examination table. Their legs were left bared and no attempt was made to immobilize them. They attempted to stay in a comfortable and relaxed situation both physically and psychologically. Concentric needle electrodes (Disa 13 K 03) used for the recording had a leading off area of about 0.04 mm² and an impedance of 50 000/−45° Ω at 5000 Hz. The main recording sites were in the short head of the biceps femoris muscle (BF) and the tibialis anterior muscle (AT) ipsilateral to the stimulation. However, the contralateral BF muscle was also included in the investigation in some cases. The position of the concentric needle electrodes was adjusted to give a minimal movement artefact and the connecting leads were stuck to the skin with surgical tape. The recording electrodes were connected to an electromyograph (Disa I4 A 30).

To evoke the flexor reflex responses, the posterior tibial nerve (PT) was stimulated electrically at the level of the ankle and in the popliteal fossa by surface bipolar stimulating electrodes (Disa 13 K 62) connected to the output of a stimulator (Disa Ministim I4 E 10). Single rectangular electrical shocks applied to the nerve trunk had a duration of 1.0 ms, a pulse duration sufficient to cause a painful sensation to the subject if the stimulus intensity were adequately adjusted. The intensity of the stimuli was progressively increased from zero to 500 V at a frequency of one per second. The procedure was repeated in the reverse direction—that is, from 500 V decreasing to zero. In this way, the evoked EMG responses were followed in the ipsilateral BF muscle. The stimulus intensity which caused a painful sensation and EMG responses of the least variability in latency and size was chosen for the final recording but, in most cases, the maximal output amplitude of the stimulator (500 V) was also used. During the recording, two kinds of stimulus frequency were used: one of them was a regular single electrical shock with 1/s frequency. Stimulation was also repeated on an irregular schedule with at least five seconds between each shock and the interval was usually 30 seconds. Five to ten superimposed oscilloscope traces as well as single sweeps from the muscles investigated were photographed on the film. In each case, at least 30 responses were obtained from each stimulation site. Sweep speeds used for recording flexor reflex responses on the film were 10 ms/mm. Sweep speeds of 5 and 25 ms/mm were also used in some cases. The distance between two stimulation sites at the ankle and the popliteal fossa along the course of the PT nerve was estimated by a plastic ruler. The room temperature was maintained around 29° C.

RESULTS

Single electrical shocks of adequate intensity delivered to the posterior tibial nerve at the ankle invariably caused a reflex response in the ipsilateral biceps femoris muscle in all subjects investigated. Figure 1 shows the reflex responses in the BF muscle recorded during successive stimulation of 1/s frequency. The discharge pattern of the double responses for each stimulation are clearly seen. The first response has a more stable latency of 100–110 ms. However, the single electrical shocks could not often produce

![FIG. 1 Reflex EMG response with double component from the right BF muscle in a normal subject. Single electrical shocks at 1/s rate to the right PT nerve at the ankle. Stimulus duration 1.0 ms and strength 500 V. The spikes have been slightly retouched.](http://jnnp.bmj.com/Downloaded from http://jnnp.bmj.com/)
Double responses such as those illustrated in BF muscle and many records from other cases were found with a single complex response consisting of a group of different motor units or repetitive firing of the same motor units, or both. As shown in Fig. 2, the suprathreshold stimulation (on left column) produced in some subjects only single motor unit response, whereas the higher intensity of stimuli made the response variable in amplitude. The earliest latencies, however, were found to be substantially constant from shock to shock (on the right column) under both conditions of stimulation. As the stimulus intensity increased, the latency of the earliest response of BF muscle became shorter in addition to the increase in size of the response (Figs 3 and 4).

Discharge pattern was also changed according to the type of stimulation. Monotonous shocks with a frequency of 1/s tended to produce the appearance of more motor units and the latency of the earliest response became slightly shorter than with stimuli delivered with irregular and longer intervals (Fig. 5). Therefore the latency values obtained by single monotonous shocks with 1/s rate were used for the measurement of conduction velocity.

**FIG. 2** Reflex EMG responses from the BF muscle on stimulation of the PT nerve at the ankle ipsilaterally in a normal subject. The single pulses of 300 V (left) and of 500 V (right) are used respectively at 1/s. At the bottom of each column, 10 oscilloscope traces are superimposed. The spikes have been slightly retouched.

**FIG. 3** Flexor reflex responses from the BF muscle on single shock stimulation of the PT nerve at the ankle ipsilaterally in a normal subject. The single pulses of 410 V (left) and of 500 V (right) are used respectively at 1/s. At the bottom of each column, 10 oscilloscope traces are superimposed. The spikes have been slightly retouched. Calibration: 0.5 mV and 100 ms.

**FIG. 4** Ten superimposed reflex responses from the BF muscle on stimulation of the PT nerve at the ankle ipsilaterally in a normal subject. Upper trace: responses evoked at 340 V; lower trace: at 500 V. Calibration: 0.25 mV and 50 ms.
EMG responses with popliteal fossa, the remaining subjects BF in of measurement that these so not did controls and at this maximal EMG responses was normal subjects (Fig. 6). Frequently less at the of longer than 200 ms 200 reflex Contralateral were sometimes BF muscle. Their with sciatica. On the other hand, reflex responses were sometimes recorded from the contralateral BF muscle. Their latencies changed from 100 to 200 ms and their discharges often indicated firing one or two motor units. They tended to appear less frequently during monotonous shocks. Contralateral reflex responses were always of longer latency than ipsilateral BF responses (Fig. 6).

The posterior tibial nerve was also stimulated at the popliteal fossa in all but three of the normal subjects and in all patients with sciatica. It was also possible to evoke clear-cut reflex EMG responses from the ipsilateral BF muscle by maximal single stimulation of the PT nerve at this proximal site. Only four of the normal controls and one patient from the sciatica group did not show responses, or their EMG discharges in BF muscle were too labile in latency and shape so that these cases could not be included for measurement of the conduction velocity. But in the remaining subjects the stimulation at the popliteal fossa, in fact, produced fairly good EMG responses with quite stable latency and size (Fig. 7). These responses were generally smaller in size as well as of shorter latencies than those obtained from stimulation at the ankle. Since the distance between two sites was known, it was possible to estimate the approximate conduction velocity of nociceptive flexor reflex afferent nerve fibres. Figures 8 and 9 illustrate the

FIG. 5 The influence of the 1/s monotonous (right) and irregular (left) single electrical shocks on the discharge pattern of right BF reflex responses. PT nerve is stimulated at the ankle ipsilaterally. Stimulus duration 1.0 ms and strength 350 V. At the bottom, five superimposed responses are shown.

FIG. 6 The stable flexor responses in the right BF muscle (I) on each electrical shock with the intensity of 500 V and 1.0 ms duration applied to the right PT nerve at the ankle; no recordable response in the ipsilateral AT muscle (II) and very unstable discharges from the contralateral BF muscle (III).

FIG. 7 Ipsilateral BF flexor responses evoked by single electrical shocks to the PT nerve at the popliteal fossa in a normal subject. Single pulses of 1.0 ms duration at 1/s. Stimulus strength is 200 V (left), 300 V (middle) and 500 V (right).
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FIG. 8 The nociceptive flexor responses from the ipsilateral BF muscle on stimulation of the PT nerve at the popliteal fossa (upper trace) and the ankle (lower trace). Five superimposed responses are illustrated in each. Stimulus duration 1.0 ms, strength 500 V, rate 1/s.

FIG. 9 The nociceptive flexor responses from the ipsilateral BF muscle in another normal subject. Stimulation of the PT nerve at the ankle (left) and at the popliteal fossa (right). At top, five responses are superimposed. Stimulus duration 1.0 ms, strength 500 V, rate 1/s.

flexor reflex responses from the ipsilateral BF muscle with different sites of stimulation in two normal control subjects. Figure 10 shows such responses recorded from a patient with sciatica. In this way, fibre conduction velocity in the fastest nociceptive afferent fibres of PT nerve associated with flexor reflexes was found to average 18.5 m/s (range 10–25.9 m/s) in 15 normal control subjects and 15.9 m/s average (range 7.7–24.3 m/s) in patients with sciatica. The statistical results for nociceptive flexor reflexes are shown in the Table. No significant difference was found between the two groups. The latencies were not significantly different (P > 0.05).

DISCUSSION

Electrical stimulation of the posterior tibial nerve at the ankle and the popliteal fossa with single shocks of 1.0 ms duration and with intensity

![Image](http://jnnp.bmj.com/)

FIG. 10 The nociceptive flexor responses from the ipsilateral BF muscle in a patient with sciatica. Stimulation of the PT nerve at the ankle (lower trace) and the popliteal fossa (upper trace). Five reflex responses are superimposed. Single electrical shocks at 1/s, duration 1.0 ms, strength 500 V. Calibration: 0.2 mV, 50 ms.

<table>
<thead>
<tr>
<th>Cases (no.)</th>
<th>Earliest reflex response latencies</th>
<th>Conduction velocity (ankle–popliteal fossa) (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal controls (mean age 28.5 yr)</td>
<td>22</td>
<td>87.5 ± 2.8 (12.8) 63.0 ± 3.8 (14.4)</td>
</tr>
<tr>
<td>Patients with sciatica (mean age 38.8 yr)</td>
<td>19</td>
<td>85.2 ± 4.3 (18.5) 59.2 ± 3.5 (15.0)</td>
</tr>
</tbody>
</table>

* Mean ± standard error of mean range.
Figures in parentheses: standard deviation.
evoking a painful sensation in the human subjects investigated has always caused a late reflex response in the ipsilateral BF muscle. These responses, recorded electromyographically, were found to appear with stimuli above the threshold of pain reported by subjects during the investigation. Higher intensity of single electrical shocks applied to the nerve were correlated with the more intense EMG responses in that muscle and the experience of pain was correspondingly felt to be increased. During regular single electrical stimulation given monotonously to the nerve, the size of the EMG responses in BF muscle and the painful sensation tended to be increased, in a stepwise manner by successive single shocks at a rate of 1/s. These clinical and electrophysiological observations indicate that the stimulation conditions used in this study have excited those afferent nerve fibres which are related to the propagation of nociceptive-painful impulses to the spinal cord.

Hugon (1967, 1973) has been able to differentiate the exteroceptive reflexes involving polysynaptic pathways, studied by stimulation of the sural nerve of man at the ankle. He often stimulated the sural nerve with a single pulse of 1.0 ms duration. This elicited a painful sensation together with a polysynaptic reflex which involved first the ipsilateral BF muscle. The latency of this response varied between 120 and 85 ms which is similar to the values we obtained by stimulation of the PT nerve at the ankle. Hugon has termed this reflex response RA III, because the features of the responses were found to involve group III skin afferent fibres. On the other hand, when he stimulated the sural nerve with a train of 6–10 weak electrical pulses producing a tactile sensation, a polyphasic response of shorter latency was again evoked in the ipsilateral BF. This response could be called RA II because of its discharge characteristics which corresponded to tactile placing reactions and involved the group II afferent nerve fibres on the afferent side of the reflex arc. RA II was found by Hugon to be very labile and it could be elicited only by a brief train of repetitive electrical shocks of weak intensity. The reflex responses elicited from the ipsilateral BF muscle by stimulation of the PT nerve in the present study are identical with the RA III obtained by Hugon on sural nerve stimulation.

Since the same features of the reflex response in the BF muscle could be obtained by stimulation of the two different sites of the PT nerve, involvement of the type of afferent nerve fibres appropriate to the RA III or nociceptive flexor reflexes is probable. Thus, the afferent nerve conduction velocity of the nociceptive flexor reflex, omitting the central delay in the spinal cord, was found to be $18.5 \pm 1.3$ (SD 4.9) m/s between ankle and popliteal fossa in 15 normal subjects and similar values were obtained from the sciatica group. The results correspond to the velocities of afferent nerve fibres belonging to group III of Lloyd, also termed A delta group of small diameter myelinated nerve fibres. These values were estimated from the shortest latencies of flexor responses of the ipsilateral BF muscle. The conclusion that the afferent nerve fibres involved in the initial part of the nociceptive flexion reflex belong to the A delta group has previously been suggested by Kugelberg (1948) and Dimitrijević and Nathan (1970). On the other hand, other investigators have thought that the flexor reflex afferent limb conduction velocity could be faster for at least the initial part of the reflex and have estimated that the conduction velocity should be more than 30 m/s. Even faster values have been proposed (Pedersen, 1954; Hagbarth, 1960; Grimby, 1963; Shahani, 1970; Shahani and Young, 1971). In some of these studies the electrical stimuli evoking flexor responses from the different muscles were often a train of successive electrical shocks and below the intensity which evoked painful sensation, so it is likely that they stimulated larger diameter skin afferent fibres involving so-called RA II responses as suggested by Hugon (1967, 1973).

A single painful shock to the PT nerve sometimes produced a double response in the ipsilateral BF muscle. This is a well-known characteristic of the human flexor reflexes (Kugelberg, 1952; Rushworth, 1962; Shahani, 1968; Shahani and Young, 1971, 1972). Sharing the idea of previous authors (Grimby, 1963; Shahani and Young, 1971) we also think that the two components are not simply a reflection of groups of faster and slower conducting afferent fibres, because the double components can be obtained by either painful or painless stimulation conditions and their latencies vary accordingly.

The method used in this study seems to be easy
and tolerable for human subjects, thus the selective evaluation of the nociceptive reflex afferent fibres can be investigated for clinical purposes.

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