SHORT REPORT

Temporal summation—the key to motor evoked potential spinal cord monitoring in humans

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Abstract

Spinal motor evoked potentials (SMEP) were recorded from tibialis anterior muscle after epidural stimulation of the spinal cord at the low cervical or high thoracic level during scoliosis surgery. By using a double stimulus pulse to produce temporal summation within the spinal cord a maximal CMAP response was readily achieved despite good surgical anaesthesia.

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The somatosensory evoked potential (SEP) has become the most widely employed method for intra-operative monitoring of spinal cord function during spinal and aortic surgery. The optimum recording characteristics have been identified,[1] and a large experience has been gained.[2] Despite a very low false-negative rate for this technique in detecting reversible spinal cord injury there are some indications from animal experimental work that the descending motor evoked potential (MEP) may give earlier warning of impending spinal cord injury.[3–5]

There have been problems with recording the MEP in humans. Although magnetic or electrical trans-cranial stimulation of the motor cortex will readily produce evoked muscle action potentials in the upper limbs, and sometimes the legs, the responses are variable and very vulnerable to anaesthesia. In addition, repeated strong stimulation of the cerebral cortex may be undesirable.

To date, spinally evoked motor potentials have had limited value because single stimuli of any reasonable intensity do not evoke maximal lower limb compound muscle action potentials (CMAPs).[3] This report describes the augmentation of lower limb CMAPs which results from paired stimuli, presumably due to temporal summation at synapses within the cord. The responses are stable and maximal and may thus form a basis for intra-operative MEP monitoring.

Methods

Spinal cord monitoring was carried out on anaesthetised patients undergoing routine corrective spinal surgery for idiopathic adolescent scoliosis. The patients were neurologically nor-

mal on routine pre-operative clinical examination and none suffered any clinically identifiable neurological deficit as a result of their operation.

Anaesthesia was induced and maintained with propofol (Diprivan, ICI Pharmaceuticals). Intubation was facilitated with a single dose of vecuronium and intra-operative analgesia was with high dose fentanyl.

Our standard method of epidural SSEP monitoring[1 2] was supplemented by recording of the spinal motor evoked potential (SMEP). For this the stimulus was applied via the bipolar catheter electrode which also acts as our standard recording electrode for the SSEP. It was placed in the upper thoracic region via a fenestration in the ligamentum flavum at the upper end of the surgical exposure and its exact location was thus known.

The recording electrodes were a pair of silver contacts 10mm by 5mm each, secured to the skin with tape over the estimated motor point of the tibialis anterior and separated by 10mm. These were connected to the differential inputs of a Medelec PA89 pre-amplifier with a reference located on the ipsilateral lower leg. The tibialis anterior was chosen so that results could be compared with most other published work on MEP monitoring. Stimulation, signal processing and display were performed by a Medelec MS91 supplying constant voltage stimuli and employing the BER filter setting (200Hz-2kHz). Responses were recorded as single sweeps without the need for averaging.

Results

Figure 1a compares the tibialis anterior CMAP responses to single and dual epidural stimuli at a number of stimulus intensities. Single stimuli, even at 125V, failed to evoke any response, whilst paired stimuli as low as 25V did so. The response amplitude was maximal at 50V but fell slightly above 75V. Latency was constant at 24 ms.

Figure 1b shows the effect of varying the inter-stimulus interval (ISI). The CMAP amplitude was maximal at an ISI of 1–2 ms and fell progressively thereafter. The form of the response remained essentially unchanged, but its latency from the first stimulus increased in exact proportion to the ISI, in other words it was fixed in its latency from the second pulse.

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Figure Surface EMG recordings from tibialis anterior in two subjects. A:Epidural stimulation at T1 vertebral level with single or dual pulses as shown on the left and right respectively, with increasing stimulus intensities. Maximal response is achieved at 50 V. B: Response to paired stimuli with increasing ISI (stimulus intensity was chosen for maximal response at ISI = 2ms). Latency increases in direct proportion to ISI.
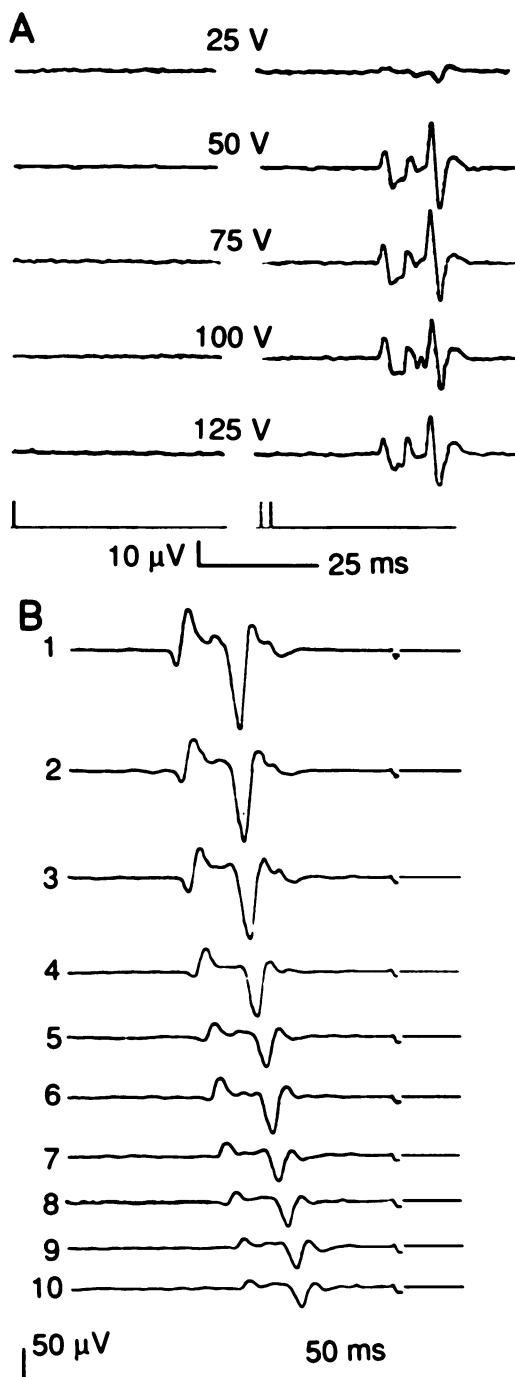
The EMG response had a complex form but it was regularly observed to have two main components, the first of which was the smaller, and their amplitudes varied together with variation in stimulus intensity and interval. The interval between the two main components for the two patients shown was nearly constant at 9·5 ms. Although the amplitude was maximal for this form of stimulation, it was somewhat below the maximal amplitude that could be obtained by direct stimulation of the muscle nerve.

Discussion

Dependable intra-operative spinal cord monitoring requires that the stimulation be reliably maximal to reduce the effect of small changes in electrode position and characteristics. An important result of the present observations is that this may be achieved with dual pulse stimulation (fig 1a), whilst single stimuli are either ineffective or unable to produce a maximal response.[3] Although it seems likely that the responses reported here depend on stimulation of descending motor pathways, it is just possible that they are due in part to antidromic conduction in muscle spindle afferent collaterals in the dorsal columns directly exciting motor neurons as in the H reflex. It has been shown that high spinal cord stimulation can evoke sciatic nerve potentials by antidromic sensory conduction.[8] Further work will be necessary to clarify this.

The SSEP results from conduction in dorsal column fibres ascending without synapse, and any action potential produced in a peripheral sensory nerve will be conducted past the cervico-thoracic recording electrode. However, motor pathways descending in the spinal cord all exert their influence on motor neurons, often via interneurons.[9] It is therefore not surprising that a single descending volley does not fire quiescent motor neurons, but that the powerful effect of temporal summation on such pathways is important.[10][11] In animal studies it is common to use a brief stimulus train at 300–1000 Hz to ensure transmission through an otherwise inactive disynaptic linkage,[12] and this study has shown that simplification of this technique to a pair of stimuli spaced at one to two milliseconds has a similar effect.

The site of temporal summation cannot be at the level of the descending axons because the optimum inter-stimulus interval is between 1 and 2 milliseconds and continues to be effective to 10 milliseconds (fig 1b). Similarly a single stimulus pulse of 500 microseconds is much less effective than a pair of 200 microsecond pulses indicating that the form of the stimulus is far more important than its energy content. Other possible sites for temporal summation are interneurons or the motor neuron. Probably both are involved, although the work of Lundberg *et al*[13] would emphasise the supralinear summation which can occur at the interneuron.

Even in the conscious subject facilitation is often required to evoke a satisfactory motor response from single central stimuli, and the greater success of MEP recording from the hand muscles may reflect the existence of direct cortico- spinal input to their motor neurons. The dependence of the spinally evoked MEP described here upon spinal neuronal function rather than simple axonal conduction may explain the greater sensitivity of the MEP than the SSEP to experimental spinal cord ischaemia.[3][5] It has been particularly noted that the MEP is lost many minutes earlier than the SSEP, and it may be more appropriate to think of the MEP as a "grey matter monitor" and the SSEP as a "white matter monitor" than the previously accepted division into "anterior" and "posterior" cord function monitors.

Conclusion

We have demonstrated that the physiological principle of temporal summation from simple paired stimuli can make spinal cord monitoring with the spinal motor evoked potential (SMEP) a practical proposition. Further work is required to explore optimum conditions of anaesthesia and to explain the precise sites and mechanisms of temporal summation within the human spinal cord before the significance of intra-operative changes in the response can be mechanisms of temporal summation within the human spinal cord before the significance of intra-operative changes in the response can be assessed.

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