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Stimulation at the cervicomedullary junction in human subjects

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Abstract

In awake human subjects, corticospinal axons can be activated at the level of the cervicomedullary junction by electrical or magnetic stimulation. Such stimuli evoke single descending volleys which activate motoneurones and elicit responses in muscles of the upper limb. These responses (cervicomedullary motor evoked potentials, CMEPs) have a large monosynaptic component and can be used to test motoneurone excitability in a variety of tasks. CMEPs can be elicited in resting muscle and during all strengths of voluntary contraction. Examination of CMEPs during and after voluntary contractions reveals changes in motoneurone excitability but also suggests activity-dependent changes in the efficacy of the corticospinal pathway. Because they test the same subcortical pathway as transcranial magnetic stimulation, but are unaffected by altered excitability at a cortical level, CMEPs often offer the most appropriate comparison to allow interpretation of changes in motor evoked potentials. The advantages and disadvantages of stimulation at the cervicomedullary junction as a test of motoneurone excitability are reviewed.

Keywords: Corticospinal; Transmastoid stimulation; Motoneurone

1. Introduction

Movement is brought about through the contraction of muscle fibres which are controlled by the firing of motoneurones in the spinal cord. Thus, knowledge of the responses of the motoneurones to synaptic input under different conditions is essential to understanding motor control. In humans, it is difficult to test the responses of motoneurones in a controlled way. The tests that are commonly used are: H-reflexes, the largely monosynaptic muscle response to activation of Ia afferents (primary muscle spindle afferents); F-waves, the muscle response to antidromic activation of motoneurones; and transcranial electrical stimulation, the short-latency muscle response to activation of corticospinal neurones by anodal stimulation over the motor cortex. Transcranial magnetic stimulation over the motor cortex (TMS) also evokes a short-latency excitatory response in muscle (motor evoked potential, MEP) through stimulation of corticospinal neurones but depends on the excitability of both cortical and spinal neurones and so cannot alone define changes in responsiveness at either level.

Although each of these responses can help describe motoneurone behaviour, each has characteristics that limits its effectiveness as a test of motoneurone excitability. The H-reflex, which is widely used, has well-described effects that can alter the afferent volley. Under many conditions there are changes in the presynaptic inhibition which acts on the Ia terminals via afferent and descending axons [39]. The Ia terminal is also affected by homosynaptic post-activation depression whereby release of transmitter from a terminal results in decreased efficacy of subsequent action potentials [19]. Finally, in conditions where there is repetitive firing of the Ia afferents, the excitability of the axons to electrical stimulation can diminish so that the same intensity stimulation no longer evokes the same afferent volley [5]. Each of these changes can alter the H-reflex response with no alteration of the motoneurones. Furthermore,

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the H-reflex can be evoked in a limited number of muscles, particularly at rest. The F-wave depends on reactivation of motoneurones after antidromic activation of the cell body. The mechanism of reactivation is poorly understood and changes in F-waves may not reflect the way the motoneurones would respond to synaptic input [21]. F-waves test a fraction of the motoneurone pool which may not include the smaller, slower motoneurones [12]. Practically, F-waves are small and multiple responses are needed to demonstrate a change in motoneurone excitability. Testing of proximal muscles is difficult because of the overlap of the large muscle response to orthodromic stimulation (M-wave) with the small F-wave. Transcranial electrical stimulation (TES) activates corticospinal neurones at the motor cortex. Low intensity stimuli activate the axons of the corticospinal neurones so that responses are unaffected by changes in cortical excitability. However, higher intensity stimuli also activate other neurones within the cortex which act synaptically on corticospinal neurones to evoke additional firing. Thus, except at very low intensities, muscle responses to TES can be affected by intracortical changes [8,24]. This limits the use of this test to small motor units and makes its use in resting muscles problematic.

Stimulation of the descending tracts at the cervicomedullary junction also evokes a short-latency excitatory response in the muscle (cervicomedullary motor evoked potential; CMEP) and can also be used as a test of motoneurone excitability in awake humans. It has some advantages over other tests, as well as its own disadvantages. The use of cervicomedullary junction stimulation, and its advantages and problems are presented below. Findings on the behaviour of motoneurones and the operation of corticospinal input revealed by cervicomedullary stimulation are also presented.

2. Electrical cervicomedullary junction stimulation

Electrical stimulation between electrodes fixed over the mastoid processes can evoke CMEPs in the muscles of the upper and, in some subjects, the lower limb [48,49]. A high-voltage electrical pulse (50–100 μs duration, up to 750 V) is passed across the spinal cord between electrodes fixed over the back of each mastoid (see Fig. 1A). Responses with the same latency are evoked with electrodes at levels between 2 cm above to 4 cm below the bottom of the mastoids. In the arms, this latency is ∼2 ms shorter than that of responses to electrical stimulation over the motor cortex and is 3–4 ms longer than that for stimulation over the motor roots [49]. The fixed latency of the response suggests that activation occurs preferentially at one site and is consistent with activation of fast descending axons at the level of the pyramidal decussation at the cervicomedullary junction. The bending of axons in the decussation makes them susceptible to stimulation at this site [1,26]. Anatomically, this is the level of the foramen magnum. Most subjects find electrical cervicomedullary stimulation unpleasant. Each stimulus is associated with a strong local muscle contraction and stimulation of skin afferents.

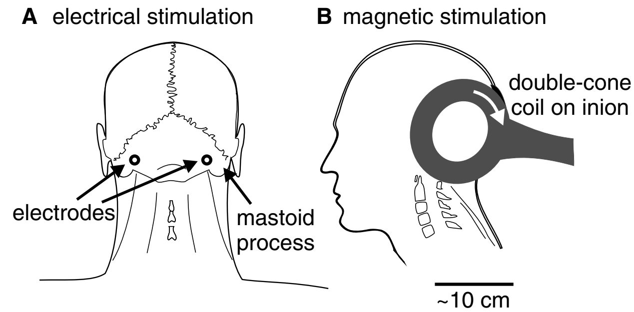

Fig. 1. Electrical and magnetic stimulation of the descending tracts at the cervicomedullary junction. A. Electrical stimulation is carried out with a high-voltage pulse passed between electrodes fixed behind the mastoids. B. Magnetic stimulation is performed using a double cone coil over the back of the head with the centre of the coil on or near the inion. The white arrow indicates the direction of current in the coil.

The most common problem with stimulation between the mastoids is activation of the ventral roots in addition to descending axons in the spinal cord [49]. The motor roots bend where they leave the spinal canal and this forms another susceptible site for activation [31,38]. Thus, as stimulus intensity is increased the site of stimulation can jump from the cervicomedullary junction to the motor root. This is seen as an abrupt decrease of ∼2 ms in the latency of the response recorded from the muscle [49]. If the axons of the motoneurones are activated distal to the cell body, their response does not depend on the excitability of the motoneurones. To ensure that responses to transmastoid stimulation are from descending axon stimulation, the latency of responses should be monitored carefully. In addition, the behaviour of the response during voluntary contraction can be helpful. CMEPs should increase in size during voluntary contraction because the excitability of the motoneurone pool is increased compared to rest [47,50] (see Fig. 2).

In the upper limbs, proximal muscles are more easily activated than distal muscles [45]. Biceps brachii can be activated with lower intensity stimuli than the hand muscles and CMEPs with amplitudes more than 50% of the maximal M-wave can be evoked even in the resting muscle (e.g. [15]). However, because proximal muscles are innervated by the higher cervical roots, which are closer to the stimulating electrodes, stimulus spread is also more likely. Responses in leg muscles (tibialis anterior, extensor digitorum brevis) to transmastoid stimulation have been reported but require high intensities of stimulation and cannot be evoked in all subjects