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Human muscle afferent responses to tendon taps

1 Characteristics of the waveform recorded with transcutaneous electrodes

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SUMMARY Responses of muscle afferent nerve fibres to tendon taps of digital muscles in the human can be recorded with surface electrodes attached to the skin over the nerve at the wrist. Using an effectively monopolar recording method, a considerable improvement in signal amplitude is achieved with simultaneous reduction in mechanical artefacts using differential amplification techniques. The characteristics of the afferent waveform (latency and duration) are discussed in relation to the applied stimulus. The contribution to the afferent response from receptors other than in the muscle have been shown to be minimal. Afferent fibres from primary muscle spindle endings are thought to be the major contributors to the afferent waveforms recorded by this technique.

Synchronous responses can be elicited from cutaneous mechanoreceptive afferent nerve fibres in the human index finger by tapping the fingernail, and such responses may be detected using surface recording techniques where the electrodes are attached to the skin over the median nerve at the wrist (Sears, 1959). However, the potential so recorded will be rather weak and may require signal averaging techniques to improve the signal to noise ratio. Similarly, it should be possible to record contributions of muscle stretch receptors by applying such mechanical taps to the muscle tendon and employing similar surface recording techniques. The phasic tendon tap is known to be a selective and adequate stimulus to the primary sensory endings of the muscle spindle (Lundberg and Winsbury, 1960; Stuart *et al.*, 1970; Matthews, 1972) and, when applied with sufficient intensity, can result in the tendon reflex. Previous investigators have either recorded directly from muscle afferent nerve fibre in peripheral nerve fascicles (Hagbarth and Vallbo, 1968; Jacobi *et al.*, 1970; Burg *et al.*, 1974), or have interpreted their contributions in averaged electromyograms recorded on the surface of the skin over a muscle while a tap was applied to the muscle tendon (Clarke *et al.*, 1972). This paper describes the characteristics of the responses to tendon taps of muscle receptors in the human first dorsal interosseous muscle recorded with surface electrodes attached to the skin over the ulnar nerve in the wrist. Studies using this technique are reported by Murthy *et al.* (1978). By employing an effectively monopolar recording technique, it has been possible to record a considerably larger signal than that obtained by Clarke *et al.* (1972) in the surface electromyogram.

Methods

The results reported here are from 15 experiments in conscious normal adult volunteers of either sex. Since we felt that attenuation by the skin and subcutaneous tissue of the potential recorded by the surface electrodes would be an important consideration affecting the signal amplitude, only subjects with thin wrists were chosen for this study. The procedures were fully explained to the subjects before each experiment, and their consent obtained.

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CHOICE OF MUSCLE

The first dorsal interosseous muscle (DI_1) which functions as an abductor of the index finger as well as a flexor of the phalanx was chosen for two reasons. Firstly, the location of the muscle is convenient for the application of tendon taps at the metacarpophalangeal point. Secondly, the DI_1 is innervated normally by the ulnar nerve and occasionally by the median nerve (Sunderland, 1968). The cutaneous innervation for the region of the index finger where the tap is applied, however, is from the branches of the radial or the median nerve. Thus, if one were to record any activity from an electrode at the wrist over the ulnar nerve, it is unlikely that the contribution of cutaneous afferent nerve fibres will be significant. One may, therefore, obtain a recording selectively of contributions from muscle receptors in the DI_1.

POSITIONING OF ELECTRODES (FIG. 1)

A standard surface electromyographic electrode (Beckman) was attached with electrode paste (Beckman) as the interface at the wrist over the ulnar nerve (U) with an identical indifferent electrode (I) over the radius. By differential recording between these two electrodes, the mechanical artefacts common to both were reduced to a minimum. Since the indifferent electrode (I) was close to the bone (radius), the contribution of field potentials due to the afferent activity in response to tendon taps was insignificant. Thus, an improvement in signal to noise ratio was achieved by this effectively monopolar recording technique compared to the bipolar transcutaneous recording methods used by earlier investigators with electrodes over the nerve (Dawson and Scott, 1949; Gilliatt and Sears, 1958; Sears, 1959), or over the muscle (Clarke *et al.*, 1972).

In some tests, the afferent activity in the median nerve was simultaneously averaged using a surface electrode (M) similar to that for the ulnar nerve. The indifferent electrode (I) was the same for both the ulnar nerve and the median nerve electrodes. The activity of DI_1 was monitored with surface EMG electrodes and played through an audio monitor which permitted the subject to maintain a near-quiescent state of motor activity in the muscle.

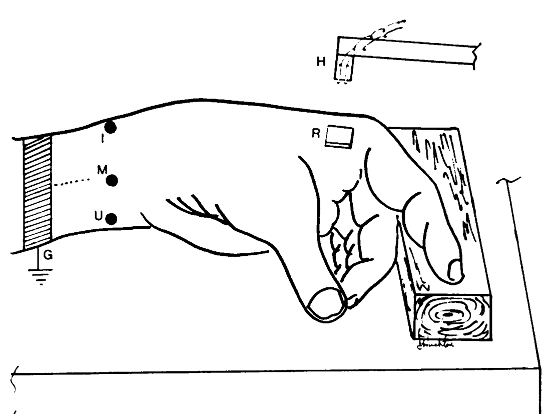

Fig. 1 *Schematic illustration of placement of electrodes over the ulnar (U) and median (M) nerves at the wrist. The indifferent electrode (I) is placed to be close to the bone (radius). The ground electrode (G) is a tinned copper plate anchored with an arm band. A conductive rubber pad (R) cushions the taps applied to the tendon of the first dorsal interosseous muscle by a lightweight hammer (H). Two metal pins attached to the hammer complete an electrical circuit with the conductive rubber pad to provide the trigger signal for the averager.*

APPLICATION OF TAPS AND RECORDING OF RESPONSE

The subjects were either sitting in a chair with the arm resting freely on the table or lying supine on a table while the tendon taps were applied. The taps were applied with a 6 inch long hammer (H, in Fig. 1) with a rubber head which had two gold-plated metal pins connected to an electrical circuit consisting of a 1.5 volt battery and a Schmitt trigger for triggering an oscilloscope (Tektronix 5103) or a signal averager (Nicolet 1072). The trigger impulse occurred when the metal pins in the hammer were shorted by contact with a conductive rubber pad (10 mm$\times$10 mm$\times$3 mm thick) that was attached to the skin with doublesided adhesive tape over the tendon of DI_1 at the metacarpophalangeal joint (R, in Fig. 1).

The potentials recorded from the ulnar nerve electrode (U) in response to tendon taps applied as above were amplified with a standard EMG amplifier (TECA, TE4) and averaged. An average of 32 sweeps was found to be adequate (see Results).

The averaged records were written out on paper using an X-Y recorder (Houston Instruments) for further analysis.

REINFORCEMENT MANOEUVRES

For confirmation of muscle spindle afferent contributions in the response to tendon taps, reinforcement manoeuvres were employed. Since the position of the subject during the test did not permit the Jendrassik manoeuvre to be performed, the subjects were instructed to flex the contralateral hand and cross the legs during the test.

They were also asked to keep the test muscle as quiescent as possible (as monitored by the audio loudspeaker) during such manoeuvres.

Results

The essential features of the waveform recorded by the percutaneous nerve electrode are illustrated in Fig. 2a. The afferent response (A) begins with a latency of 4 to 5 ms, reaches a maximum in another 8 to 10 ms, and then decays in the next 10ms. The entire waveform thus described must be due to afferent nerve fibres responding to the mechanical taps of the tendon since it lasts for less than 20ms which should be the minimum time required for any motor response occurring as a reflex. Also, only light taps were used for obtaining the waveform in Fig. 2a, ensuring minimal reflex response as determined in simultaneous surface EMG recordings from the muscle (DI_1). The separation of the afferent contribution (A) from the efferent reflex response (R) is clearly demonstrated in Fig. 2b which was obtained in a subject who was not fully relaxed during the test, the DI_1 exhibiting some basic EMG activity.

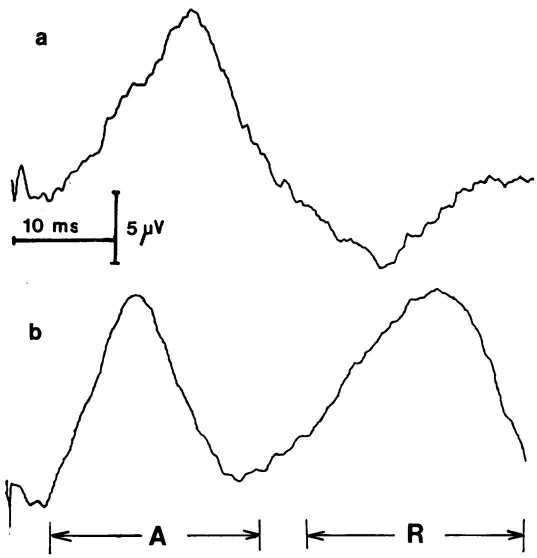

Fig. 2 *Afferent waveform (A) in response to tendon taps applied to the DI_1 muscle (a) in the absence of a reflex response (R) and, (b) accompanied by a reflex response. The records are from the activity recorded by the ulnar nerve electrode and averaged (32 sweeps).*

A certain amount of variability in the afferent response is to be expected from the variable character of the applied mechanical stimuli. The hammer was not automated. However, the qualitative features of the recorded waveform were reproducible with signal averaging techniques. It is obvious that the degree of signal improvement would be proportional to the number of sweeps averaged. It was decided to limit this number to 32 since the tests could then be conducted within a short period of 30–40 seconds in which a reasonable constancy of fusimotor bias to the spindle endings could be assumed. Figure 3a illustrates the differences in the afferent response averaged over 32 or 128 repetitions of the stimulus. The taps were sufficiently light to elicit little or no reflex response. Figure 3b illustrates the effect of a reinforcement manoeuvre, again averaged over 32 or 128 sweeps. It is clear that while the qualitative features of the averaged waveforms are the same in both cases—that is, control and during reinforcement manoeuvre—factors like latency of response and amplitude are variable. It is particularly obvious in Fig. 3b that the latency of onset of response averaged over 128 sweeps is considerably larger than that averaged over only 32 sweeps. Variability in fusimotor drive may be one of the reasons, although the variability in strength of stimulus may be equally responsible. What is interesting, however, is the change in the afferent response to tendon taps during the reinforcement manoeuvre (Fig. 3b), in comparison with the control (Fig. 3a) when the subject was relaxed. The afferent response appears to be sharpened with a slight decrease in latency of onset. It is also apparent that there is a facilitation of the reflex response.

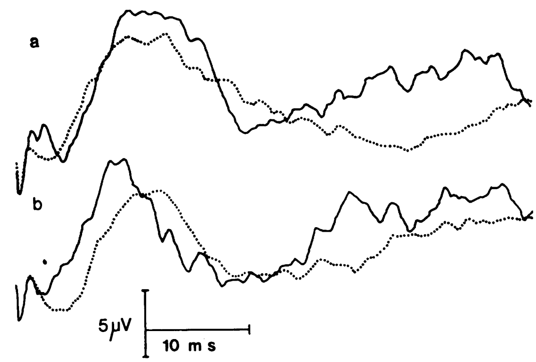

Fig. 3 *Comparison of the afferent responses to tendon taps with the averaging 32 sweeps (solid curves) or 128 sweeps (dotted curves): (a) subject relaxed, and (b) subject performing a reinforcement manoeuvre (see text).*

The confirmation of afferent nerve fibres from muscle spindles as the major contributors to the waveform recorded as above was obtained by employing xylocaine to anaesthetise first the skin and tendon, and subsequently the muscle. Figure 4a shows that the taps applied over the skin adjacent to the muscle tendon, but not directly over it, do not produce any significant response in the waveform recorded percutaneously from the ulnar nerve. On anaesthetising the skin and the DI_1 tendon, tendon taps are still effective in eliciting the afferent response (Fig. 4b) which was abolished by infiltrating the muscle belly with xylocaine. At this point a needle electrode was inserted into the muscle for recording (Fig. 4c), and a weak afferent contribution could be detected. This response could, however, be enhanced by a reinforcement manoeuvre (Fig. 4d) that also caused a reflex response. This was clearly visible in the transcutaneous nerve recording performed simultaneously (Fig. 4e). The afferent contribution is also detectable in the transcutaneous nerve recording during the reinforcement manoeuvre (Fig. 4e).

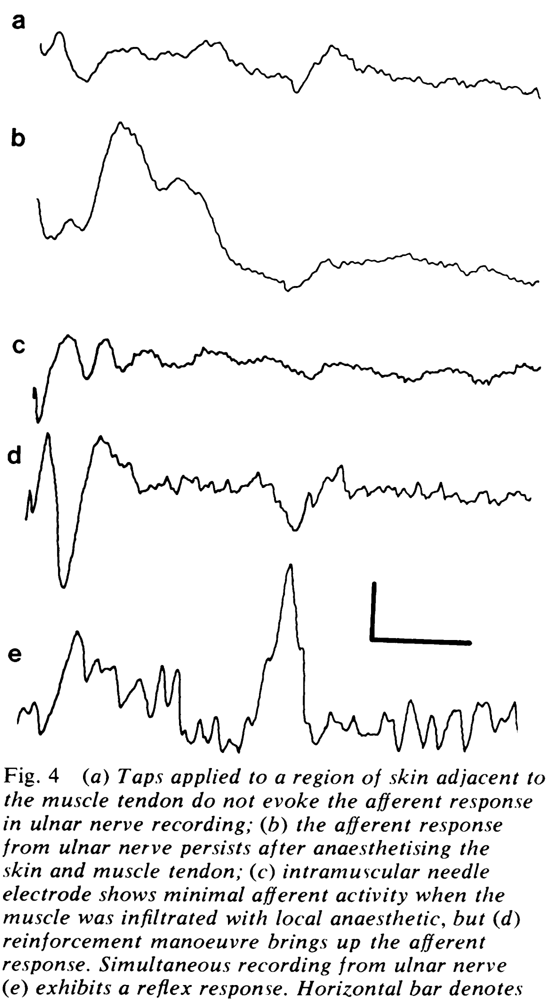

Fig. 4 *(a) Taps applied to a region of skin adjacent to the muscle tendon do not evoke the afferent response in ulnar nerve recording; (b) the afferent response from ulnar nerve persists after anaesthetising the skin and muscle tendon; (c) intramuscular needle electrode shows minimal afferent activity when the muscle was infiltrated with local anaesthetic, but (d) reinforcement manoeuvre brings up the afferent response. Simultaneous recording from ulnar nerve (e) exhibits a reflex response. Horizontal bar denotes 10 milliseconds. Vertical bar calibrates 5 microvolts for a, b, and e, and 50 microvolts for c and d. All traces are averages of 32 sweeps each.*

Discussion

The contribution of muscle spindles to the recorded waveforms in response to the tendon taps is to be expected due to the well-established responsiveness of the primary endings to phasic mechanical stimuli (Lundberg and Winsbury, 1969; Stuart *et al.*, 1970; Matthews, 1972). Questions may arise, however, regarding the latency and duration of the afferent waveforms. The first afferent impulse in response to a brief phasic stretch of the muscle occurs with a minimum latency of 2 ms and could be delayed for as long as 4 or 5 ms after the stimulus (Paintal, 1959). The length of ulnar nerve from the position of the recording electrode to its point of entry into DI_1 in the present experiments must have been in the range of 100–120 mm. With a maximum conduction velocity of 70–80 metres/s for the primary afferent fibres (Magladery and McDougal, 1950; Buchthal and Rosenfalck, 1966; Goto *et al.*, 1968; Willer, 1975), it should take another 1.2 to 1.8 ms for the impulses to reach the recording electrodes. In addition, the hammer did not strike the skin directly because a rubber pad was applied to the skin over the tendon. A further delay of up to 2 ms for the mechanical stimulus to reach the receptor may thus be expected. That this is not an overestimate is shown by the waveform recorded with surface electrodes over the muscle (Fig. 5). The waveform, which starts with a latency of 4 ms, may be similar to that described by Clarke *et al.* (1972).

The duration of the afferent response in the transcutaneous nerve recording is in the range of 10–15 ms, and is probably due to a burst of impulses from a number of receptors activated by the mechanical stimulus. This conforms with earlier observations from multiunit recordings made with intranerve microelectrodes (Hagbarth and Vallbo, 1968; Jacobi *et al.*, 1970; Struppler and Erbel, 1972), or from the surface electromyogram (Clarke *et al.*, 1972). Figure 6 illustrates schematically the time relationships between the stimulus and the afferent response. While the

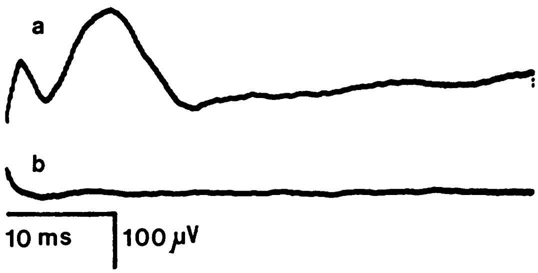

Fig. 5 (*a*) *Waveform recorded on the surface of the muscle illustrates timing of the afferent response after the tap;* (*b*) *the same electrode records no response to taps applied to the nail of the index finger.*

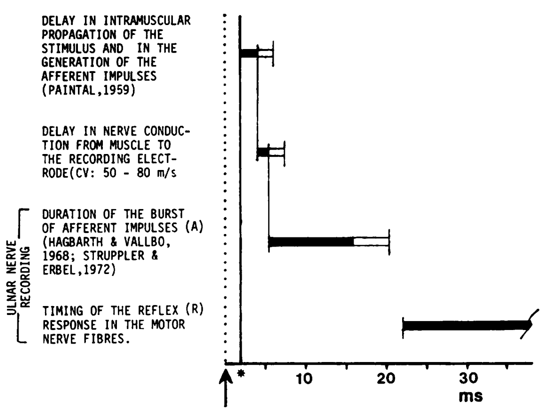

Fig. 6 *Schematic reconstruction of the time relationships of afferent and reflex contributions to the waveforms recorded with surface electrodes at the wrist. Solid bars represent minimum range and the open bars the maximum range. Arrow indicates the instant of contact between the hammer and the rubber pad. Time between arrow and asterisk indicates the presumed delay for the stimulus to reach the tendon.*

spindle response to tendon taps will not be a synchronous discharge as obtained with electrical stimuli, there will definitely be a number of impulses occurring within the 20 ms after the mechanical stimulus, producing a near-synchronous discharge from a number of receptors.

Applying the tendon taps to the DI_1 muscle and recording from the ulnar nerve also presents the experimenter with the unique situation of being able to avoid recording contributions of cutaneous or joint afferent fibres, and to record selectively from muscle afferent fibres. Since the phasic tendon tap, when applied at low strengths, is a selective stimulus for the primary spindle receptors, the technique is useful in the study of the responsiveness of spindle primary endings in humans. The effectiveness of the recording technique presented here has been further tested under various situations of changes in fusimotor drive (Murthy *et al.*, 1978). An important requirement for stable and reliable recordings using this technique is that the surface electrodes are not disturbed after they are attached to the skin at optimal positions.

A recording from the median nerve using similar electrodes may also show a similar response as with ulnar nerve recording. Contributions from the infrequent branches innervating the DI_1 muscle may be observed in the median nerve recording. In addition, it may contain responses of afferent fibres from neighbouring lumbrical muscles and also from cutaneous receptors.

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