Peripheral projections of sensory fascicles in the human superficial radial nerve

M. Campero,[1] J. Serra[2] and J. L. Ochoa[3]

[1]*Department of Neurological Sciences, Universidad de Chile, Santiago, Chile,* [2]*Neuropathic Pain Unit, Hospital General de Catalunya, Barcelona, Spain and* [3]*Oregon Nerve Center, Good Samaritan Hospital, Portland, OR, USA*

Correspondence to: Dr M. Campero, Departamento de Ciencias Neurológicas, Universidad de Chile, J. M. Infante 553, Providencia, Santiago, Chile
E-mail: mcampero@med.uchile.cl

Summary

The sensory territories of different cutaneous fascicles of the superficial radial nerve were delineated by microneurography at the level of the distal forearm in humans. Three fascicular patterns were found at this level: one supplying the dorsum of the radial aspect of the dorsum of the hand over the first dorsal interosseous space; another supplying the lateral aspect of the first metacarpal extending to the lateral aspect of the thumb; and a third innervating the second interosseous space and the proximal phalanx of the index and middle fingers. The compound fascicular territory is comparable to the classical territory described for the superficial radial nerve. Intraneural microstimulation of individual fascicles did not evoke paraesthesiae or pain beyond their fascicular territory, regardless of the stimulus intensity. We conclude that the superficial radial nerve at the forearm in man is composed of only three fascicles, as shown by the present study and from previous anatomical work. Referred pain seems related to nerve activity in afferent fibres from fascicles supplying deep tissues and muscles, not from cutaneous afferents.

Keywords: nerve; fascicle; microneurography; intraneural stimulation; receptive field

Introduction

Anatomical studies have shown that nerve fibres within a nerve trunk are subdivided into well defined fascicles, ‘which by repeatedly uniting and dividing, engage in a plexus formation along the full length of a nerve’ (Sunderland, 1945). The expected result would be that the more distal the fascicle the less likely it would be that the common topographic arrangement would be found. However, the fascicular receptive fields of individual fascicles in the human median nerve, recorded both at wrist and arm level, do not exceed the area of one or two digital nerves (Schady *et al*., 1983; Moore and Schady, 2000). Eleven cutaneous fascicular patterns have been described in the ulnar nerve in humans (Marchettini *et al*., 1990), all of which cover a continuous area of skin. The sum of the different fascicular receptive fields makes up the cutaneous territory of the median and ulnar nerves. In the present paper, we describe the fascicular cutaneous territory of the superficial radial nerve in humans. These results complement previous studies on the fascicular cutaneous innervation of the hand. In contrast to the referred pain evoked by intraneural stimulation of mixed motor and sensory fascicles in the median (Schady *et al*., 1983; Torebjörk *et al*., 1984) and ulnar (Marchettini *et al*., 1990) nerves, intraneural microstimulation of sensory fascicles of the superficial radial nerve, at painful levels, elicits sensations projected only to the cutaneous territory of that nerve.

Methods

Twenty-two experiments were performed on eight healthy volunteers (one female, seven males) and six patients (four females, two males) affected by neurological disorders not involving the radial nerves and without CNS disorders affecting sensory discrimination. All volunteers and patients gave informed consent and the local ethics committee approved the study. All experiments were performed at distal forearm level where the superficial radial nerve turns posteriorly beneath the tendon of the brachioradialis muscle appearing on the dorsum of the forearm, superficial to the abductor pollicis longus muscle (Sunderland, 1978). Microneurographic recordings were obtained from the superficial radial nerve at the distal forearm, as described in detail elsewhere (Vallbo and

Hagbarth, 1968). In brief, the subjects sat relaxed with the arm firmly supported. Intraneural recordings were obtained using a disposable lacquer-insulated tungsten microelectrode, 200 µm in diameter (FHC, Bowdoinham, ME, USA) that was inserted manually through the skin into the nerve. A subcutaneous reference electrode was inserted 1–2 cm away. The neural signals were amplified, audio-monitored, displayed on an oscilloscope (Tektronix 5113) and stored on magnetic tape (Hewlett-Packard, model 3968A) for off-line analysis. An intraneural position of the electrode was ascertained by the presence of paraesthesiae projected to the cutaneous territory during microstimulation with square-wave electrical pulses of 0.25 ms duration at 3 Hz, and around 0.3 V intensity. In pilot experiments it was observed that, during intraneural microstimulation, the area of projected sensation of a fascicle of the nerve was comparable to the area of skin from which neural activity was recorded, provided the bandpass filter was set between 0.3 and 10 kHz and the window discriminator was fully open. Since the area of maximal projected sensation was similar or slightly smaller (Marchettini *et al*., 1990) than the area of the fascicular receptive field, it was assumed that it corresponded to a fascicular territory. The borders of the cutaneous receptive fields were then delineated with coloured ink, photographed and copied to a template. The compound receptive field was obtained by superimposing each single fascicular receptive field.

Then, intraneural microstimulation was given at threshold level with square-wave electrical pulses at 3–5 Hz delivered through the recording electrode in the same intrafascicular position. The stimulus intensity was increased in steps until detection threshold was reached (usually around 0.3 V). It was then further increased to clearly suprathreshold pain levels. The subject was asked to describe the characteristics and distribution of the projected sensation. Finally, the intrafascicular position of the electrode was reconfirmed by switching to recording mode from the same sensory fascicle.

Results

Twenty-three sensory fascicles were identified by microneurography, all of which could be grouped in three different anatomical patterns. One fascicular pattern ($n = 8$) covered the radial aspect of the dorsum of the hand over the first dorsal interosseous space (Fig. 1, top). Among these fascicles, one (number 6 from right to left, top to bottom) covered, to some extent, the second dorsal interosseous space, but the main area covered the first dorsal interosseous space. These fascicles extended up to the proximal interphalangeal joint of the index finger. A second pattern ($n = 8$) covered the dorsal aspect of the hairy (and to a lesser extent glabrous) skin of the first metacarpal extending to the lateral or medial aspect of the thumb (Fig. 1, middle). Six of the eight fascicular patterns extended to the dorsum of the thumb to cover the nail bed. A third fascicular pattern ($n = 7$) comprised the skin of the second dorsal interosseous space innervating up to the proximal interphalangeal joint of the index and middle fingers from its dorsal aspect (Fig. 1, bottom). Only the fascicle supplying the first metacarpal in two subjects also covered 1–2 cm of hairy skin towards the palm.

The sizes of individual fascicular receptive fields varied in maximal diameter from 1 to 8 cm. The largest fascicular territory covered the radial aspect of the dorsum of the hand, while the smallest supplied the second dorsal interosseous space. The sum of all fascicular receptive fields covered the entire radial aspect of the dorsum of the hand, extending into the lateral aspect of the dorsum of the middle finger and the dorsum of the index finger up to the proximal interphalangeal joint (Fig. 2).

Intraneural microstimulation of the different fascicles at 3 Hz at threshold level evoked a painless or nearly painless tapping sensation projected to corresponding receptive fields, never extending to adjacent territories. As in pilot studies, the area of projected sensation was always smaller than or similar to the cutaneous fascicular receptive field of individual fascicles. At higher intensities, the evoked sensation became painful, with an intermittent tapping-pressure sensation and additionally an unpleasant pseudocramp referred to deep structures, such as tendons or bones underlying the fascicular receptive field. Occasionally a burning pain was evoked with the same distribution. Regardless of the stimulus intensity, the evoked sensation, whether tactile or pain, was always projected to the fascicular receptive field. In no case was there pain referred to remote areas.

Discussion

The fascicular arrangement of sensory fibres in the median and ulnar nerves in humans demonstrates that nerve fibres grouped in one single fascicle supply a continuous area of skin, and not separate cutaneous territories, as might be expected by anatomical studies (Sunderland, 1945). Although the total number of fascicles determined by intraneural microstimulation for the human median nerve has not been directly measured, the sensory fascicular territory resembles the innervation area of a single palmar digital nerve or a digital interspace (Schady *et al*., 1983). For the human ulnar nerve (Marchettini *et al*., 1990) it was possible to identify by microneurography 11 sensory fascicular patterns covering the skin of the hand. 'Several' small fascicles are described in the cutaneous division of the ulnar nerve at the wrist in anatomical studies (Sunderland, 1978).

Sunderland (1978) described a constant pattern of three 'funiculi' in the proximal 1.5 cm of the separate superficial radial nerve, while in proximal segments the bundles containing fibres of this branch occupied the anterior pole of the radial nerve. Although the number of fascicles in distal segments of the superficial radial nerve is not specified, the present results indicate that the nerve at the level of the distal forearm contains only three sensory fascicles.

The most distal branches of the superficial radial nerve in one anatomical study (Bas and Kleinert, 1999) have been described to extend up to the nail bed of the thumb in every case; in nearly a third of the cases the branches extended to the nail bed of the index finger and in a very few they reached this level in the middle finger. In the present work, fascicles covering the distal phalanx of the index finger were

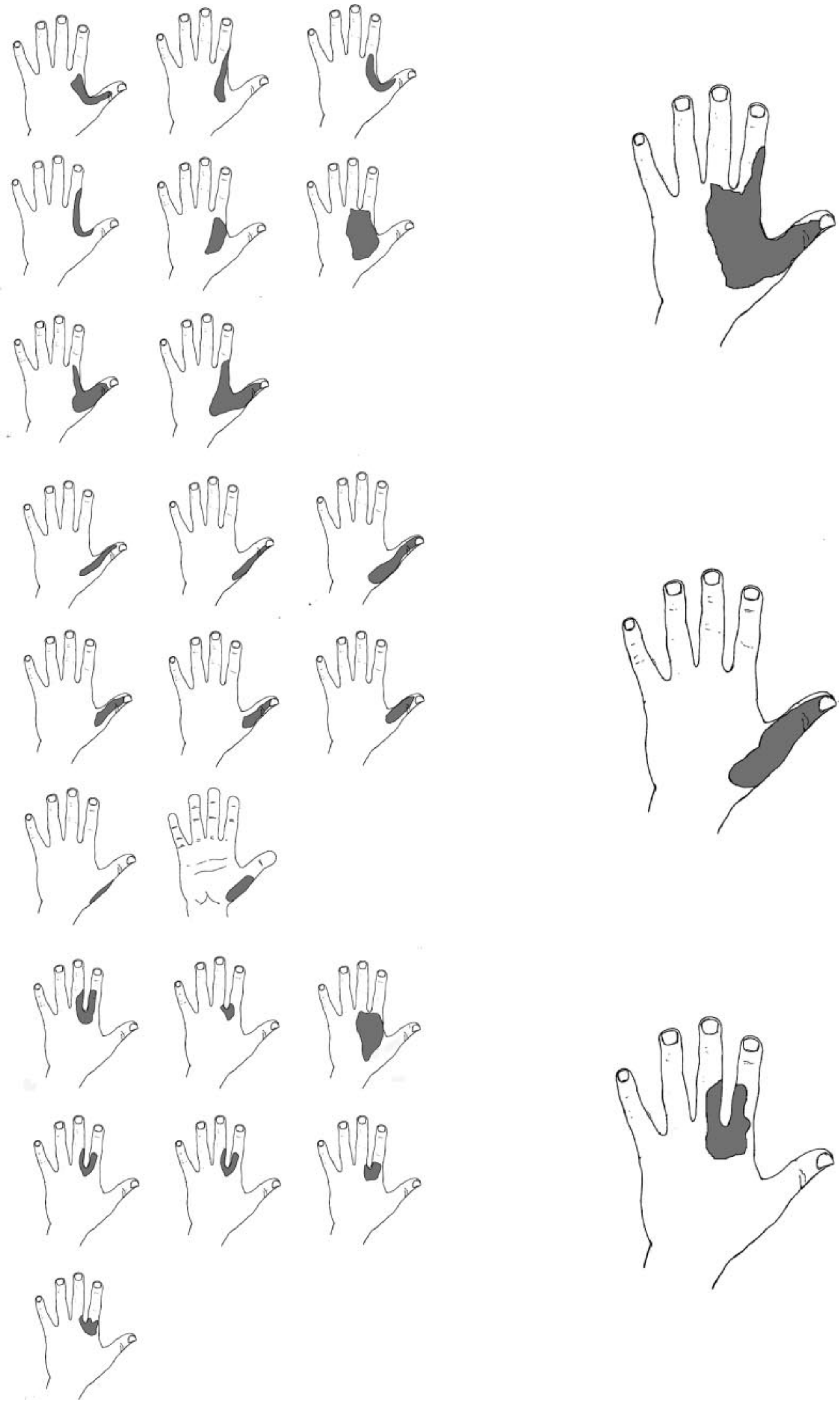

Fig. 1 (*Left*) Area of 23 individual cutaneous fascicles delineated using microneurography in 14 subjects. These fascicles covered the first interosseous space and, to some extent, the base of the thumb (*top*), the thumb alone (*middle*) and the second interosseous space and the base of the index and middle fingers (bottom). (*Right*) Composite of the sum of all fascicular territories of each of the three pattern distributions.

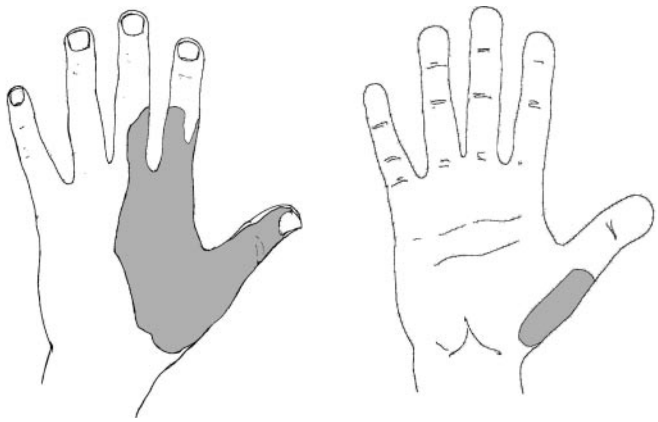

Fig. 2 Total area of cutaneous territory of the superficial radial nerve covering the radial dorsum of the hand, the dorsum of the index and middle fingers and the dorsum of the thumb. One fascicle extended slightly to the glabrous skin of the thenar eminence.

not found, although, considering our small sample number, fascicles extending further distally may exist.

The compound cutaneous receptive field of the superficial radial nerve as delineated by the present method is equivalent to the known anatomical territory of the human superficial radial nerve (Haymaker and Woodhall, 1953). It was found that the cutaneous territory never extended to the ulnar aspect of the dorsum of the hand or to the median innervated distal dorsum of the fingers. One narrow area in the hand dorsum between the ulnar and superficial radial territory might still be supplied by a distal branch of the posterior antebrachial nerve, as suggested by Pollock and Davis (1933).

Fascicular microstimulation of either the median or the ulnar nerve is able to evoke pain referred to remote areas, provided that the fascicle innervates muscle and deep structures. It has been proposed that convergence of group III and IV afferents in second-order neurons in the spinal cord is one of the mechanisms underlying this referred pain (Torebjörk *et al*., 1984). Pain induced by microstimulation of cutaneous afferents has not been described to evoke referred pain, but a distorted sensation may occur under experimental conditions (Torebjörk *et al*., 1992). In line with previous findings (Schady *et al*., 1983), intraneural microstimulation of afferent fibres in different fascicles in the superficial radial nerve did not evoke pain beyond the anatomical territory of the nerve.

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