G Model
AANAT-50831; No. of Pages 6

ARTICLE IN PRESS

Annals of Anatomy xxx (2013) xxx–xxx

Contents lists available at ScienceDirect

Annals of Anatomy

journal homepage: www.elsevier.de/aanat

Research article

Median nerve fascicular anatomy as a basis for distal neural prostheses

Uwe Planitzer[a,b,*,1], Hanno Steinke[a,1], Jürgen Meixensberger[b], Ingo Bechmann[a], Niels Hammer[a], Dirk Winkler[b]

[a] Institute of Anatomy, University of Leipzig, Liebigstraße 13, D-04103 Leipzig, Germany
[b] Department of Neurosurgery, University of Leipzig, Liebigstraße 20a, D-04103 Leipzig, Germany

ARTICLE INFO

Article history:
Received 24 July 2013
Received in revised form 6 November 2013
Accepted 22 November 2013
Available online xxx

Keywords:
Anatomy
Electrical stimulation
Median nerve fascicles
Prosthesis
Rehabilitation

ABSTRACT

Introduction: Functional electrical stimulation (FES) serves as a possible therapy to restore missing motor functions of peripheral nerves by means of cuff electrodes. FES is established for improving lower limb function. Transferring this method to the upper extremity is complex, due to a lack of anatomical data on the physiological configuration of nerve fascicles. Our study's aim was to provide an anatomical basis for FES of the median nerve in the distal forearm and hand.
Methods: We investigated 21 distal median nerves from 12 body donors. The peripheral fascicles were traced back by removing the external and interfascicular epineurium and then assigned to 4 quadrants.
Results: A distinct motor and sensory distribution was observed. The fascicles innervating the thenar eminence and the first lumbrical muscle originated from the nerves' radial parts in 82%. The fascicle supplying the second lumbrical muscle originated from the ulnar side in 78%. No macroscopically visible plexus formation was observed for the distal median nerve in the forearm.
Conclusions: The findings on the distribution of the motor branches of the median nerve and the missing plexus formation may likely serve as an anatomical basis for FES of the distal forearm. However, due to the considerable variability of the motor branches, cuff electrodes will need to be adapted individually in FES. Taking into account the sensory distribution of the median nerve, FES may also possibly be applied in the treatment of regional pain syndromes.

1. Introduction

Functional electrical stimulation (FES) serves as a possible therapy for restoring missing functions of peripheral motor nerves by means of cuff electrodes (Hart et al., 2006; Kottink et al., 2007; Mangold et al., 2009; Mann et al., 2011; O'Halloran et al., 2003; Thrasher et al., 2008). Functional deficits can partially be restored by means of FES, supporting the neurologically impaired to regain their independence in everyday activities (Chan et al., 2009; Kottink et al., 2007). A fundamental prerequisite for accomplishing successful FES is the profound anatomical knowledge of the peripheral architecture of the nerve of interest. The reliability of FES depends on this knowledge (Gustafson et al., 2005, 2009, 2012).

One possible target of FES is the distal forearm and the palmar aspect of the hand. This region is supplied by the median nerve, which controls the ability to grasp an object and the major function of the thumb (Mumenthaler et al., 2007). The median nerve arises from the ventral roots of the fifth cervical to the first thoracic spinal nerve, originating from the brachial plexus. In the hand, the median nerve has efferent (motor) branches to the muscles of the thenar eminence and to the 2 radial lumbrical muscles. With its sensory branches on the palmar side of the hand, the common or proper palmar digital branches, the median nerve supplies digits 1–3 and the radial side of the fourth: dorsally and distally, the median nerve supplies digits 2–4. The palmar cutaneous branch (PCB) of the median nerve does not run through the carpal tunnel, and is therefore not affected in carpal tunnel syndromes (Mumenthaler et al., 2007). The above-mentioned distribution corresponds to the norm of the median nerve innervation area. There are many variations in the anatomical course of the median nerve in the region of the carpal tunnel and the hand (Davlin et al., 1992; Lanz, 1977).

However, the internal structure of the median nerve has been insufficiently described with conflicting results in present

Abbreviations: d, dorsal; FES, functional electrical stimulation; FM, flexor muscles of the forearm; FR, flexor retinaculum; MN, median nerve; MTE, muscles of the thenar eminence; n, sample size; p, palmar; PCB, palmar cutaneous branch; r, radial; S, skin; SPA, superficial palmar arch; TE, motor fascicle to the thenar eminence; u, ulnar.

* Corresponding author at: Institute of Anatomy, University of Leipzig, Liebigstraße 13, D-04103 Leipzig, Germany. Tel.: +49 341 97 22086; fax: +49 341 97 22009.
E-mail address: uwe.planitzer@medizin.uni-leipzig.de (U. Planitzer).

[1] These authors contributed equally to this work.

0940-9602/$ – see front matter © 2013 Elsevier GmbH. All rights reserved.
http://dx.doi.org/10.1016/j.aanat.2013.11.002

literature. In the past, the internal anatomy of the peripheral nerves of the upper limb was investigated by means of micro-dissection by some authors (Jabaley et al., 1980; Sunderland, 1945). The focus of these studies was to understand the internal structure to obtain an anatomical basis for improving the outcome of nerve transplantations. The internal plexus formation of peripheral nerves was described, showing that its internal structure is incomparable to the previous conception of a simple cable structure. The fascicle configuration in the median nerve is not parallel as the fascicles change their location within the course of the nerve (Sunderland, 1945). These observations might influence the feasibility of FES at the distal arm by complicating the predictability of the stimulation, which has to be taken into account.

The aim of our study has been to describe motor and sensory fascicular topography of the median nerve in the distal forearm to provide an anatomical basis for median nerve stimulation. The following issues were addressed:

(A) Where does fascicular plexus formation end for the median nerve and which location of the median nerve is consequently most suitable for selective peripheral nerve stimulation?
(B) Can median nerve fascicles be distinguished by macroscopic dissection?
(C) How reliable is fascicular distribution, considering the median nerve's cross-section in the distal forearm?

2. Materials and methods

Twenty-one median nerves from 12 body donors (11 left arms and 10 right arms) were investigated at the Institute of Anatomy, University of Leipzig. While alive, all donors had given their informed consent to the donation of their bodies for teaching and research purposes. The mean age of the body donors was 84 (mean) ± 6.32 (standard deviation) years (range 76–95 years). Eight donors (7 left arms, 6 right arms) were female and 4 donors (4 left arms, 4 right arms) were male. Parts of the arms were already dissected in the gross anatomy course. All but one subject was examined in an ethanol–glycerin-fixed state (Hammer et al., 2012), the remaining one in a fresh unfixed condition.

2.1. Specimens in the unfixed condition

For determining the location at which plexus formation starts in the median nerve, one right forearm was investigated in the unfixed condition. The external and interfascicular epineurium was removed from the nerve, beginning in the antecubital fossa and then dissecting distally along the nerve toward the carpal tunnel (Fig. 1).

2.2. Ethanol–glycerin-fixed specimens

After removing the arms ($n = 20$) from the trunk, the PCB of the median nerve was visualized as a landmark. Then, the branching of the median nerve was dissected according to the approach of Bezerra et al. (1986), starting at the branching of the PCB and proximal to the rascetta. The distal forearm and the hand were removed from the arm, proximal to the site where the PCB originates. This complied with a distance of approximately 80 mm from the distal wrist crease (own unpublished results). We then incised the proximal part of the median nerve at the removed distal forearm with a scalpel under 2.3× magnification (C 2.3® binocular loupe, Heine Optotechnik, Herrsching, Germany) to determine its cross-section. The cross-sections were sub-divided into 4 quadrants: palmar radial, palmar ulnar, dorsal ulnar and dorsal radial, respectively. The proximal ending of each branch was fixed with a clamp, representing each of the 4 quadrants. Then the peripheral

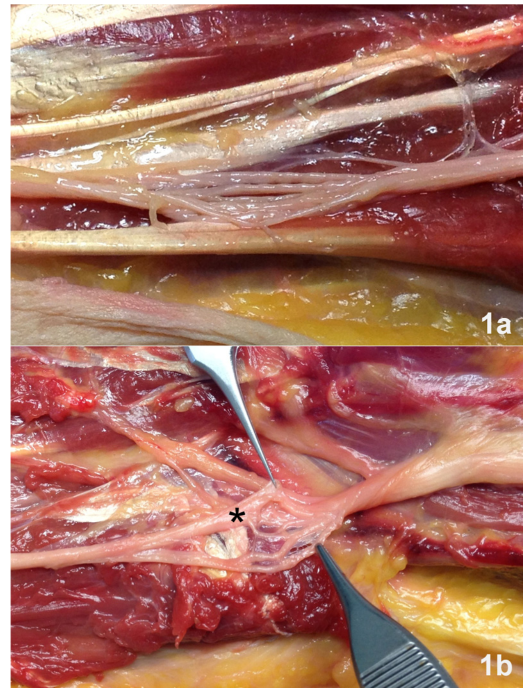

Fig. 1. Depiction of the median nerve fascicles in the forearm in the unfixed condition. (a) In the distal forearm, amounting to the retinaculum, no plexus formation was macroscopically visible and (b) in the antecubital fossa a marked plexus formation (*) was seen.

branches of the median nerve were dissected under magnification. After complete dissection of the distal median nerve branches, we traced back each branch proximally and removed their covering external epineurium. The interfascicular epineurium of the median nerve could now be removed. Tracing back the peripheral fascicles, we then attributed each fascicle to the quadrants (Fig. 2). Doing so, the distal insertion sites of the motor and sensory fascicles could be assigned to the nerves' cross-sections.

2.3. Statistics

Pearson's chi-squared test for independent variables was used to investigate equal distribution of the nerve fascicles between the assigned quadrants. *P* values of 5% or less were considered as statistically significant.

3. Results

3.1. Location of median nerve plexus formation

In the forearm that was dissected in the anatomically unfixed condition, the median nerve fascicles showed no macroscopically visible plexus formation distal to the antecubital fossa (Fig. 1a). In contrast, a marked plexus formation was observed proximal to the antecubital fossa (Fig. 1b).

3.2. Separation of motor and sensory fascicles

The distance between the separation of the PCB and the most distal wrist crease averaged 45 mm (range 16–69 mm). Distinguishing motor from sensory fascicles was possible by determining the insertion sites of the nerve. When assigning the fascicles to the 4 quadrants, all of them originated from 1 quadrant or from 2 adjacent quadrants. Eight combinations of fascicle origin were seen: (1) radial palmar, (2) radial dorsal, (3) ulnar palmar, (4) ulnar dorsal, (5) radial and ulnar palmar, (6) radial and ulnar dorsal, (7) radial