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Anatomical compartmentalization of the human peroneus longus muscle in cadaver dissection

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Many skeletal muscles have been found to be composed of smaller portions of a muscle innervated by a primary muscle nerve branch called neuromuscular compartments. The purpose of this study was to identify the anatomical evidence for neuromuscular compartments of the human peroneus longus muscle. Eight legs from human cadavers donated were dissected. The architectural characteristics of muscle fiber direction and tendinous tissue were examined. The primary nerve branching pattern throughout the peroneus longus was also observed. The peroneus longus was found to have four distinct partitions. The superficial portion and deep portion within the muscle were separated by an aponeurosis that is continuous with the distal tendon. Furthermore, each of these both portions was partitioned into two portions by muscle fiber orientation. In addition, these architectural compartments of the muscle were congruent with compartments identified by innervation pattern. The present findings suggest that intramuscular compartments of the peroneus longus are anatomically defined. In future, this muscle's partitioning will not only lead to an anatomical foundation for the physiological study to elucidate the functional multiplicity of the peroneus longus, but also provide a scientific rationale for establishment of more specific protocols for rehabilitation of patients with the dysfunctional muscle and muscle atrophy.

Key Words：Peroneus longus, Neuromuscular compartments, Gross anatomy

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ヒト長腓骨筋内のコンパートメントを同定する肉眼解剖学的研究

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近年、多くの骨格筋が神経筋コンパートメントと呼ばれる要素から構成され、これらの筋区画は機能的な要求に応じて選択的に活動することが確認されつつある。本研究では、ヒト長腓骨筋の筋内コンパートメントを肉眼解剖学的に同定することを目的とした。筋標本は解剖実習用固定屍体の下腿8肢を使用し、筋線維走行、腱組織の位置関係および筋内の神経分岐様式を観察した。その結果、長腓骨筋は独立した神経枝の支配を受ける４つの区画を有することが認められた。筋内の浅部および深部区画は、停止腱から続く腱膜によって分離される。さらに、これらの両区画の各々が筋線維の走行により前部と後部区画に区分される。今回試みた解剖学的な筋のコンパートメント化は、長腓骨筋内に存在する機能的分化を示唆する。また、筋機能不全や筋萎縮を呈する患者に対して、この筋内コンパートメントを指標として画像検査や筋電図学的評価を行うことは、効率の良い最適な理学療法プログラムの構築に寄与すると考えられる。

＜キーワード＞　長腓骨筋、神経筋コンパートメント、肉眼解剖

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Ⅰ. Introduction

Most mammalian skeletal muscles have been found to be composed of smaller elements called neuromuscular compartments, which are distinct subvolumes of a muscle, each innervated by an individual muscle nerve branch and each containing motor unit territories with a unique array of physiological attributes[1]. Morphological studies on human muscles identify subdivisions based on a muscle architecture and innervation patterns. Dissection of the human biceps brachii revealed both architectural and nerve branching pattern compartmentalization within the muscle[2]. In the human tibialis anterior muscle, because the muscle shows variations in innervation patterns among specimens, three distinct partitions of the tibialis anterior may be defined only by its architecture[3].

In addition to the presence of the anatomical compartments within the muscle, some studies have showed that the each neuromuscular compartment of a whole muscle plays independent different functional roles. Electromyography (EMG) and force analysis of muscle on both animal and human models have been used in order to determine the function of neuromuscular compartments, suggesting that the intramuscular compartments were functionally partitioned through possible, differential partition activation and directionally generated torque[4,5].

With respect to the compartmentalization of the peroneus longus muscle, physiological studies in animal models have found evidence to suggest that this muscle may be partitioned. In the hindlimb muscle peroneus longus of cats, electromyographic activity recorded from anterior and posterior regions of the muscle during voluntary motor behavior demonstrated that the task-associated differences exist in the intramuscular EMG distribution[6]. Thus, the purpose of this study was to identify the anatomical evidence for neuromuscular compartments of the human peroneus longus muscle in cadaver dissection. The expected significance resides in the possibility that this work may contribute to functional examinations to detect specific portions of the muscle most responsible for generating various motions at the ankle joint. Furthermore, knowing the architecture of intramuscular portions would provide an anatomical basis to determine the ultrasound scanning sites and to interpret the obtained images in detail when performing the ultrasonographic study to investigate the dynamic nature of the human peroneus longus in vivo. This ultrasound scanning may be applied to the clinical evaluation of muscle function assessed by physical therapists. Ultimately, physical therapists would be able to selectively stimulate and retrain the muscle via its compartments more related to dysfunctional movements, rather than treat the entire muscle.

Ⅱ. Materials and methods

Specimens were obtained during harvesting sessions from eight perfused human cadavers donated to the Sapporo Medical University, Department of Anatomy. The donated cadavers ranged in age from 68 to 90 years. Four of the eight cadavers were male and four were female.

The peroneus longus muscle specimens were observed in situ for gross muscle fiber orientation and main muscle nerve. The muscle specimens then were removed from the cadavers. The muscle specimens were tagged identifying the age and gender of the donating cadaver and the side of the body (right or left) from which the muscle specimen was harvested. After removal from the body, all specimens were placed in plastic containers and fully immersed in phenoxyethanol solution.

After all specimens were harvested from the cadavers, fat and fascia were removed and preliminary observations of each whole muscle were made. Dissection then was performed to observe the muscle fiber direction, muscle nerve innervation, locations of tendon and aponeurosis in each muscle specimen. Sketches, written descriptions and photographs were made to document the presence, location and characteristics of muscle fiber orientation and tendinous inscriptions. Portions of muscle containing an exclusive primary nerve branch, differing muscle fiber orientation and tendinous inscriptions were described as anatomical partitions.

Ⅲ. Results

In all eight legs, the peroneus longus had four distinct architectural regions, and these regions are identified as anterior superficial (AS), posterior superficial (PS), anterior deep (AD) and posterior deep (PD) portions (Fig. 1). The superficial portion and deep portion within the muscle were separated by an aponeurosis that is continuous with the distal tendon. Furthermore, each of these both portions was partitioned into the anterior and posterior portions by muscle fiber direction. The AS, PS and AD portions are approximately located in the proximal one half of the whole muscle length. The other PD portion originates a few centimeters distally from the proximal end of muscle belly and terminates on the distal end of the muscle. In addition,

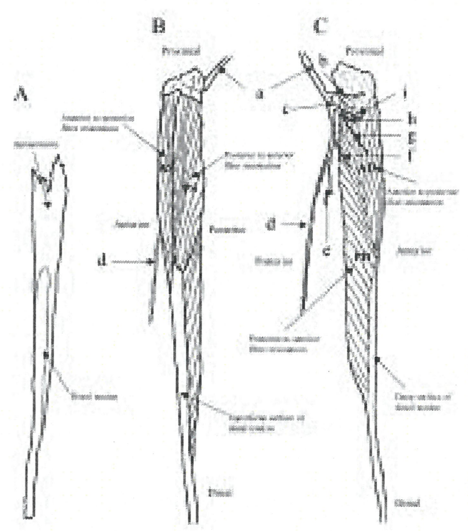

Fig. 1. Drawings of the peroneus longus muscle showing its architecture and innervation. A The extent of the dividing aponeurosis which is continuous distally with the tendon. This aponeurosis separates the superficial portion of the neuromuscular compartment from the deep portion. B Superficial view of the muscle includes muscle fiber orientation, tendinous inscription and motor nerve. Architectural portion of the peroneus longus: AS, anterior superficial portion; PS, posterior superficial portion. The aponeurosis is hidden underneath the fibers of portions AS and PS in this view. C Deep view of the muscle. Architectural portion of the muscle: AD, anterior deep portion; PD, posterior deep portion. See Figure 2 for labels.

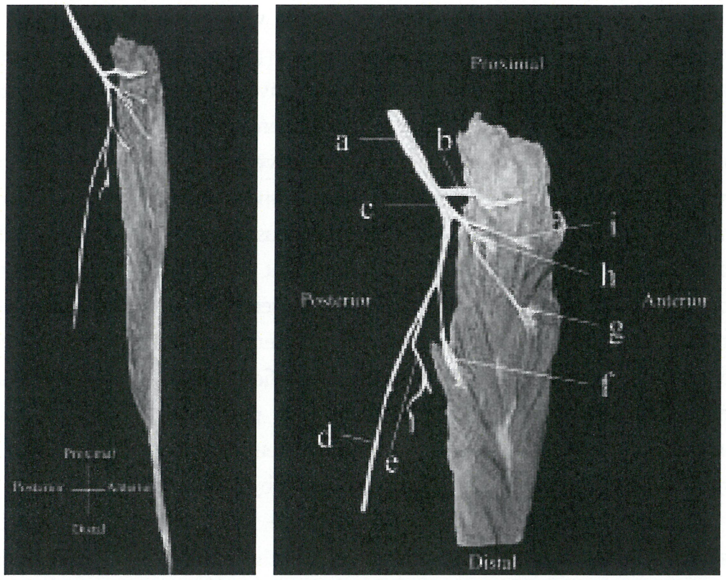

Fig. 2. Photographs of a left human peroneus longus muscle. A Whole deep view of the muscle showing a typical innervation pattern. B Deep view of more proximal aspect of the same specimen as in A. This photograph reveals a primary nerve branching pattern. a, common fibular nerve; b, deep fibular nerve; c, superficial fibular nerve; d, cutaneous branch of superficial fibular nerve; e, muscular branch to the peroneus brevis; f, muscular branch to the PD; g, muscular branch to the AD; h, muscular branch to the PS; i, muscular branch to the AS. Some of the muscle fibers from the AD and PD portions have been reflected so that the innervation becomes apparent.

the most fibers within each portion of the four muscular compartments are oriented from oblique to slightly longitudinal from distal-to-proximal.

Four primary motor branches innervate each portion of the muscular compartments of peroneus longus (Fig. 2A, B). The common fibular nerve (Fig. 2B, a) splits into its superficial and deep fibular nerves (Fig. 2B, b) before any other branches were encountered. The superficial fibular nerve (Fig. 2B, c) runs deep to the peroneus longus giving off the motor branches to it. The nerve then continues down the lateral side of the leg deep to the peroneus longus and superficial to the peroneus brevis. At this point it usually gives off a branch to the peroneus brevis (Fig. 2B, e) and continues as the dorsal cutaneous branch of the foot (Fig. 2B, d). Typically, the first branch of the superficial fibular nerve supplies the AS portion of the peroneus longus (Fig. 2B, i). The second branch of the superficial fibular nerve is the motor branch to the PS portion of the muscle (Fig. 2B, h). The third branch of the superficial fibular nerve supplies the AD portion of the muscle (Fig. 2B, g). The fourth branch of the superficial fibular nerve found in this study is the motor branch to the PD portion of the muscle (Fig. 2B, f).

Even though the entry points of the motor branches into each portion of the muscle are variable, their points are consistently found to be in the proximal half of the muscular portions. While a typical pattern of these branches was perceived, there was some variability as to the order of the branches as they arise from the superficial fibular nerve. Also, these motor branches may start as common branches from the parent nerve, but always split up before entering their respective portions of the muscle.

Ⅳ. Discussion

Recent data by Bakkum et al.[7] derived from investigation performed preliminarily in human cadaveric model have provided the existence of partitions based mainly on the innervation pattern and connective tissue in the peroneus longus muscle. They confirmed the division of human peroneus longus into four segments for all of forty-three embalmed adult cadavers dissected. However, architectural partitions based on characteristics of muscle fiber orientation within the peroneus longus muscle have not been found in both human and animal studies. Also, the relation between the muscle architecture and the nerve branching patterns remains unknown. Therefore, the present work was designed to examine whether there is morphological partitioning evidence that may assist functional investigations of the neuromuscular organization in the human peroneus longus. Dissection of the peroneus longus revealed both architectural and nerve branching pattern compartmentalization within the muscle. The result is that the peroneus longus is partitioned, at least grossly, into four distinct muscular portions defined on the basis of architectural evidence. These architectural compartments are further innervated by separate four nerve branches from the superficial fibular nerve. The primary muscle nerve branching pattern of innervation observed in this study is also consistent with the typical innervation pattern identified previously by Bakkum et al[7]. Moreover, the architectural and nerve branching pattern compartments are congruent. Thus, the present findings suggest that the human peroneus longus muscle is architecturally organized into the anatomical neuromuscular compartments. If future physiological studies will demonstrate that these anatomical compartments can behave differently according to movement performance, then the notion that neuromuscular compartments represent the functional elements controlled by the CNS in the design of skeletal muscles, as first proposed by English and Letbetter[8] for cat ankle extensor muscles, can be extended to the human peroneus longus muscle. Moreover, the architecturally defined four portions of a muscle supplied by an independent primary nerve branch suggest the existence of multifunctional consequences of the peroneus longus muscle.

The peroneus longus is clinically important muscle located in the lateral side of the leg. Konradsen et al.[9] and Neptune et al.[10] evaluated electromyographically the role of the human peroneus longus during sudden inversion and cutting movements susceptible to ankle sprain but did not consider the placement of electrodes based on compartments. Also, although the CSAs of the peroneus longus in patients with peroneal paresis and forefoot pes cavus were assessed using ultrasonography[11] and MRI[12], their imaging investigations were not based on intramuscular compartments as identified in the present findings. In any event, the existence of muscular compartments as a principle of muscle organization provides reasons to rethink the understanding of how muscles truly operate and refine the therapeutic approaches possessed by therapists and clinicians. Using only the traditional notion of muscle origin and insertion as the factor determining the action and direction of movement may limit optimal evaluation and treatment of movement abnormality within the neuromuscular system.

Collectively, understanding the details of anatomical neuromuscular organization is thought of great practical importance, not only to provide the substrate to carry out functional experiments elucidating a basic motor control in humans, but also to aid in the detailed interpretation of static or dynamic muscular images using MRI, computed tomography scanning, or ultrasound imaging, to provide a scientific rationale for development of more specific protocols for rehabilitation after injury, to provide an anatomical basis for electrode placement for EMG recordings, functional electric stimulation.

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