早稲田大学審査学位論文

博士（スポーツ科学）

概要書

Three-dimensional orientation of human medial gastrocnemius fascicles and its functional significance

人間の腓腹筋内側頭における筋束の 3 次元走行とその機能的意義

２０２３年１月

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Skeletal muscle fascicles are often oriented obliquely within muscle belly, forming pennate architecture. Significance of the pennate architecture in mechanical function of skeletal muscle has long been considered using simple geometric models in which fascicles show angulation only in the sagittal (perpendicular to the aponeurosis) plane. In such models, the fascicle sagittal angulation is considered to contribute to 1) maximal force-generating capacity, 2) belly gearing (amplification of fascicle length change to muscle belly length change), and 3) increases in aponeurosis width and longitudinal stiffness in active state. However, fascicle may be angulated in not only sagittal but also coronal (parallel to the aponeurosis) planes. Furthermore, the fascicle coronal angulation would lead to the rotation in the coronal as well as sagittal planes during movements. Nevertheless, these points are poorly understood. The purpose of this thesis was to clarify 3D architecture and mechanics of human medial gastrocnemius (MG) which is known as a typical pennate muscle.

In Chapter 3, fascicle 3D architecture was examined in human MG at resting state *in vivo*. The reconstructed fascicles demonstrated non-zero angles both in sagittal and coronal planes, showing 3D orientation. Combining the fascicle coronal angulation with the sagittal angulation resulted in greater fascicle cross-sectional area relative to the attachment area as compared to the sagittal angulation alone. In Chapter 4, fascicle 3D mechanics was examined during passive elongation of human MG *in vivo*. The results demonstrated that the fascicles rotated in not only sagittal but also coronal planes during passive elongation of the muscle belly. Similar to the fascicle sagittal rotation, the coronal rotation contributed to the amount of passive muscle belly elongation. In Chapter 5, 3D mechanics of fascicles and deep aponeurosis was examined during active shortening of human MG *in vivo*. The results showed that fascicles rotated in the sagittal as well as

coronal planes, contributing to the amount of muscle belly shortening. Furthermore, the fascicle coronal angulation and rotation enabled force transmission along the mediolateral direction, and its increase with muscle belly shortening. At the same time, the aponeurosis increased the width in addition to length.

The findings in each chapter indicate that pennate muscle fascicles are oriented in 3D space with angles both in the sagittal and coronal planes. Furthermore, the fascicle coronal angulation changes during passive elongation and active shortening of muscle belly, highlighting that the fascicle coronal angulation leads to the coronal rotation during muscle belly length change. Similar to the fascicle sagittal angulation, the coronal angulation in pennate muscle may have a positive influence on the maximal force-generating capacity and belly gearing. On the other hand, the fascicle coronal angulation enables the mediolateral force transmission potentially promoting increases in the aponeurosis width and longitudinal stiffness. This could eventually contribute to the efficiency of force generation during movements. Such functional significance is unique to the fascicle coronal angulation in pennate muscle. The present findings considerably motivate to change the current paradigm, highlighting novel 3D aspects of the significance of pennate architecture in mechanical function of skeletal muscle.