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The 3D architecture of muscle fascicles in selected muscles and its relevance to force production

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ABSTRACT

Introduction

Biomechanical models describing muscle characteristics are very complex and different techniques like *forward kinematics, inverse kinematics* and *finite element method* were used in the past. None of them take all influential 3D features into account, such as the fibre type distribution or the geometrical arrangement of the muscle fascicles. In particular, the arrangement of the fascicles has an influence on the force production of the muscle [1, 2, 3, 4, 5]. The aim of this study was to reconstruct and compare the 3D architecture of the muscle fascicles between relaxed and contracted muscles and to document possible internal inhomogeneities. The data will be incorporated into a 3D muscle model in order to gain a better understanding of the contraction behaviour of the musculature. As a result, complex courses of muscle action can be simulated and help to understand pathological alterations or evolutionary changes regarding the energy efficiency and the mobility of the musculoskeletal system.

Methods

The M. gastrocnemius medialis and M. soleus of the rat (*Rattus norvegicus* Wistar) were investigated under experimental conditions. The muscles were shock-frozen in the relaxed or contracted condition. From serial-cross-sections, the muscle fibre bundles were reconstructed and evaluated as 3D polynomials using different techniques (Fig. 1).

Results & Discussion

The detailed geometry of the two muscles was measured in high resolution in both, the relaxed and the contracted condition. The variation of the polynomials contains information about the pinnation angle and the curvature of the fascicles as well as their geometrical deformation. The muscles showed locally different pinnation angles and curvature distributions, and these parameters changed during contraction (Fig. 2).
The results show specifically that many models oversimplify the muscle's architecture. This simplification ignores local differences in the pinnation angles which have an impact on a muscle's contraction properties. Moreover, because these local

architecturally different regions may be innervated differently and may act in so called neuromuscular compartments [6, 7, 8], a detailed, lifelike muscle model has to take the local differences into account. Additionally, local differences impose a problem on the determination of the PCSA, as it can not be determined exactly. Because the fascicle curvature varies between the proximal and the distal muscle parts, comprehensive curvature data are essential to more detailed muscle models. The results provide a data base to create improved, i.e. more detailed, muscle models such as a Finite Element Mesh incorporating further parameters.

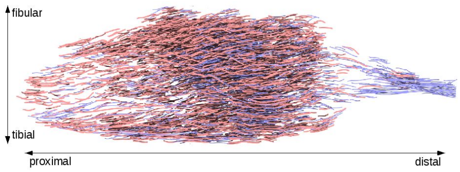

Figure 1: The fascicle arrangement in the contracted M. gastrocnemius medialis.

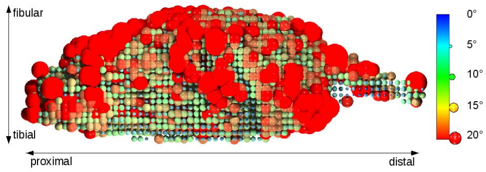

Figure 2: The distribution of the 3D angles in the contracted M. gastrocnemius medialis.

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