SENSITIVITY STUDY OF THE HILL MUSCLE MODEL IN A MUSCULOSKELETAL SHOULDER MODEL

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Introduction

A significant part of the shoulder stability is provided by the rotator cuff (RC). A torn RC, often resulting in strong impairment during daily activity, can be treated with a RC repair, however, a re-tear occurs in 20-70% of the cases depending on its severity [1]. Tear size, shape, and retraction but also degree of muscle atrophy, fatty infiltration and tendon quality are decisive factors for a RC repair outcome. However, it is not yet well understood how they influence the repair outcome and why some patients show a poor functionality after repair. The effect of these risk factors on muscle physiology after RC repair can be assessed using musculoskeletal simulations with the Hill muscle model. However, before repair simulations can be performed, the sensitivity and interplay of the Hill model parameters need to be understood. Thus, the aim of this study is to evaluate the sensitivity of the Hill muscle model parameters on supraspinatus strength during shoulder abduction.

Methods

The modelling of the shoulder was performed in AnyBody Modeling System (ver 7.3.4, AnyBody Technology A/S, Aalborg, Denmark) [2]. The initial working range of the shoulder muscles was set by defining the optimal muscle fiber length and tendon slack length using a two-parameter calibration [3]. After calibration, ideal muscle strength (F_0), optimal fiber length (Lf_0), tendon slack length (Lt_0), tendon strain at F_0 (ε_0) and fraction of fast twitch fibers (Fc_{fast}) were 70.2N, 4.8cm, 8.6cm, 5.3% and 40%, respectively. Subsequently, they were varied ±25%, ±50% and ±75% to assess their effect on the course of supraspinatus (SSP) strength from 0° to 120° of shoulder abduction.

Results

After calibration, SSP strength peaked with 280N at 20° abduction and subsequently continuously decreased with increasing abduction angle (Figure 1, Table1). F_0 varied overall muscle strength but not its course. When Lf_0 increased, the strength of the SSP increased and the peak shifted to a lower abduction angle. At 50% and 75% increase of Lf_0, SSP strength peak shifted to a negative abduction angle and thus the SSP strength at 0° abduction decreased. Changing from an ε_0 of -75% to +75% decreased SSP strength by 28N or 10% of its initial strength and shifts the peak by 20° to higher abduction angles.

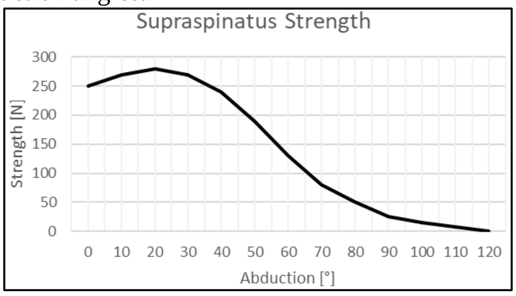

Figure 1: SSP strength during 120° arm abduction.

Discussion

We herein present a study of the effect of Hill parameters on muscle strength. The model was most sensitive to changes in muscle fiber (Lf_0) and tendon length (Lt_0), with peak strength varying and shifting strongly from 0° to 120° abduction In contrast, variations in tendon stiffness had only a minor effect on the course of the supraspinatus strength. Sarcomere stretch and contraction explain these variations. These findings can be used to guide parameter selection for future RC repair simulations.

References

1. Aurora et al, J Shoulder Elb Surg, 16: 171-178, 2007.
2. Damsgaard et al, Simul. Model. Pract. Theory, 14(8): 1100-1111, 2006.
3. Garner et al, Ann Biomed Eng, 31: 207-220, 2003.

	Peak SSP Strength [N] at shoulder abduction height [°]				
ΔParameter	**F_0**	**Lf_0**	**Lt_0**	**ε_0**	**Fc_{fast}**
-75%	80N [20°]	80N [120°]	100N [120°]	267N [30°]	235N [20°]
-50%	150N [20°]	225N [95°]	305N [120°]	270 [27°]	255N [20°]
-25%	220N [20°]	240N [60°]	275N [70°]	275 [23°]	270N [20°]
initial			280N [20°]		
+25%	350N [20°]	300N [0°]	180N [0°]	285 [17°]	290N [20°]
+50%	430N [20°]	210N [0°]	10N [0°]	290 [13°]	300N [20°]
+75%	490N [20°]	120N [0°]	0N [0°]	295N [10°]	310N [20°]

Table 1: Peak supraspinatus strength [N] at abduction height [°] initially and after ±25%, ±50% and ±75% variations of muscle strength (F_0), fiber length (Lf_0), tendon length (Lt_0), tendon strain at F_0 (ε_0) and fast twitch fibers fraction (Fc_{fast}).