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Muscle interaction in the context of muscle deformation modelling by a Position Based Dynamics method

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1 Introduction

Helping medical professionals decide whether to perform invasive surgery on the musculoskeletal system and prevent dire health consequences can be achieved through a computerised musculoskeletal model. One such musculoskeletal system based on a Position Based Dynamics method (PBD) presented by Kohout and Červenka (2021) exhibits unnatural bending of the *iliacus* muscle being passively dragged in a rag-doll manner during hip flexion. Therefore, the main focus of this thesis is to extend the current PBD-based simulator to support muscular interactions, where the muscles synergistically contract and relax, while also avoiding collisions.

2 Analysis Overview

The muscles being modelled are skeletal muscles mostly made of striated muscle fibres. Consider that even just to keep the hip joint stable, all the *periarticular* muscles are co-activated in a group called the muscular fasteners of the hip joint. As Kapandji et al. (2019) describe, muscular synergies during movement tend to be even more invested. The muscles are elastic and their geometries deform during movements. But to model a deformable object also means to decide on the structure and the method to deform that structure over time under external (e.g. gravity) or internal (e.g. tension) forces appropriately. Both these factors can put limitations on the solutions.

3 Proposed Solution

This thesis proposes solutions to two problems of the current PBD 3D surface triangular mesh muscle deformation model. The first problem is the **penetration of elastic muscle objects** in the scene, rarely addressed in the state-of-the-art musculoskeletal models, usually resulting in unrealistic states of the complex muscle geometries. The second problem is the absence of active intermuscular interactions facilitated through governed synchronous activations (contractions) of the muscles, currently, the state-of-the-art muscle models are **mere passive followers of the bone movements**.

Avoiding the **penetration of elastic muscles** is a form of **passive intermuscular interaction**. The muscles can not intersect as this is highly unrealistic. Stochastic-based, structureless, fast and effective algorithm of Virtual Edges solves this unfeasible problem. Virtual Edges between the muscles take advantage of *a priori* anatomical and physiological reality of the muscles, as they should only come into contact in predictable areas. The edges try to minimise their length by traversing the vertex neighbourhoods on each side in a zig-zag fashion. When

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a **C**ontact **P**roximity **D**istance is reached, a possible collision is detected and avoided.

Muscles being unnaturally dragged and unnaturally bent in shape can greatly affect the lengths of the extracted inner fibres of the surface muscle, which may be crucial for biomechanical analysis. Physiologically-based modelling of **active contraction in groups of muscles** is one of the plausible solutions. The muscle activation estimates are sampled using the **OpenSim 4.5 Static Optimization Tool** under various bone orientations. During the simulation, muscle activations for the current bone orientations are interpolated from the samples and projected onto the muscles. The muscles produce contraction or relaxation based on that activation via shortening distance constraints, representing surface approximations of their inner muscle fibres. If the samples are realistic (and cover the orientation space well), so are the muscle contractions.

4 Results and Conclusion

The results were rigorously verified for visual plausibility, adherence to the physiology of muscle interaction, correspondence to the results of a similar method, and preserving muscle shapes and volumes. The quality of the proposed muscle penetration avoidance method was also assessed. The verification was conducted on four of the provided muscles, during five basic leg movements (flexion, extension, abduction, and internal rotation). Moreover, the behaviour of the resulting extracted inner muscle fibres was compared with the previous PBD model, which showed improvements, especially for the *iliacus* muscle (see Figure 1). All the implemented propositions proved successful in their original ambitions, surpassing the idea of the method being a mere proof of concept, as its outcomes seem to show great signs of applicability to real, biomechanical systems.

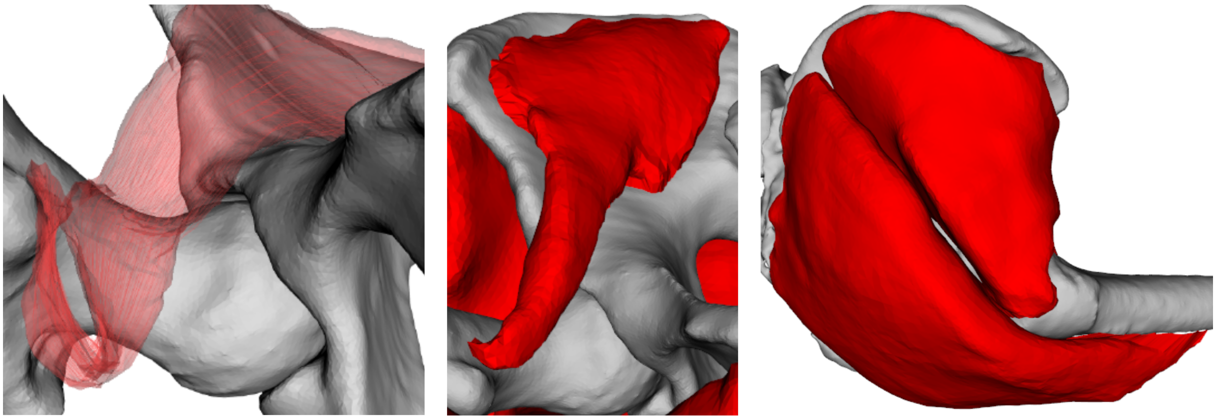

Figure 1: Former unnatural *iliacus* bending, proposed solution result for a similar same pose, and muscle penetration avoidance (respectively)

References

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