Biomechanical model for musculoskeletal simulation

Megdi Eltayeb[1,a] *

[1]Department of Mechanical Engineering, Prince Mohammad Bin Fahad University

[a]meltayeb@pmu.edu.sa

Keywords: Biomechanical, Musculoskeletal, Modeling, OpenSim

Abstract. Musculoskeletal modeling is a technique for studying joint contact forces and moments during a movement. Subject-specific models can achieve high accuracy in estimating joint contact forces. Construction of subject-specific models, on the other hand, remains costly and time-consuming. The objective of this study was to determine what changes could be made to generic musculoskeletal models to improve the estimation of joint contact forces. The effect of these changes on the accuracy of the estimated joint contact forces was evaluated. A variety of change strategies were discovered, including muscle models (e.g., muscle length), joint angle models (e.g., angle, number of degrees of freedom), moments and optimization problems (e.g. objective function, constraints, design variables). All of these changes had an effect on joint contact force accuracy, demonstrating the potential for improving model predictions without requiring time-consuming and expensive medical techniques. However, due to inconsistencies in the literature evidence about this effect, and despite the high quality of the reviewed studies, no trend defining which change had the greatest effect could be identified.

Introduction

Movement is essential to human and animal life and is produced by the interaction of complex neural, muscular, and skeletal systems. Movement research draws on and contributes to diverse disciplines, including neuroscience, biology, robotics and biology. OpenSim combines methods from these fields to generate accurate and fast movement simulations, enabling two essential tasks. First, building a model can predict new trends. Second, compute variables that are hard to calculate during movement. OpenSim is a software package that is extensible and user-friendly, based on decades of experience in computational simulation and modelling of biosystems. It allows computational researchers to create new innovative tools and use these tools in research and applications. OpenSim helps a large and growing community of scientists exchange models for reproducing and growing research. It is possible to discover strategies to improve performance and prevent injury by studying the biomechanical structures that control underlying movement. The benefits are improved rehabilitation for patients after a stroke [1]; musculoskeletal analysis and for optimizing assistive devices [2, 3]; musculoskeletal injuries [4, 5]; as well as biomechanical interpretations [6, 7]. In order for scientists to make progress in the field of movement science, they have to develop tools that integrate computational modeling and simulation tools from a variety of disciplines such as robotics, mechanics, and computer science. There are a number of open-source software packages available for collecting and analyzing experimental movement data (e.g., OpenMA [4] and BTK [5]) but this kind of software is less suited for simulations and optimizations.

In addition to providing research with biomechanical models and simulation tools, OpenSim facilitates the advancement of movement science. There are several main areas of functionality within OpenSim. It is possible for users to create and manipulate biomechanical models. As an example, musculoskeletal models can be constructed using this software [6]. It is also necessary to simulate the dynamics of the musculoskeletal system. It is possible for researchers to conduct experiments that are impossible to conduct experimentally through simulations. Researchers are investigating how humans and animals exploit tendon elasticity to make running more efficient [7-9] and optimizing the design of implantable mechanisms and assistive devices [10-13]. Additionally, it is capable of predicting novel movements and adaptations to novel conditions without the need for any experiments. Through the study of loaded and inclined walking, this capability has allowed a deeper understanding of muscle coordination [14]. Furthermore, it provides insight into the limitations of reflexes when it comes to the prevention of ankle injuries when landing [20]. In addition, it provides suggestions for enhancing jumping performance with optimum device design [15]. In addition, improved computational models, numerical methods, and simulation tools will be developed and shared to extend the capabilities of the software.

Methods

OpenSim software is licensed under the Apache License 2.0, which permits its reuse for a variety of purposes, including non-profit and commercial applications. Community members are encouraged to contribute to the source code, which is available for free and anonymously on GitHub. The musculoskeletal model, freely available in OpenSim (http://opensim.stanford.edu/) was evaluated in this study. This model included a generic gait model. The generic model was gait2392 [16]. This model is based on gait2392 with the addition of the obturator and rectus abdominus muscles. Adjustments were also made to the muscle geometry so that the moment arms of the model matched experimental measurements. Model generalized coordinates that best reproduced the experimental marker coordinate data for each trial were computed by solving an inverse kinematics problem. This global optimization algorithm is formulated as a least-squares problem that minimizes the differences between the measured marker locations and the model's virtual marker locations, subject to joint constraints. Inverse dynamics was performed using the measured ground reaction forces and inverse kinematics results to calculate the intersegmental moments. Muscle forces were estimated using static optimization to minimize the sum of squares of muscle activation at each instant in time. The peak and root-mean-square of each reserve actuator were verified to be less than 5% of the net moment calculated via inverse dynamics. Estimated muscle activations were then verified via qualitative comparisons between the model-based predicted activations and experimental electromyographic data provided in the HIP98 dataset as per current recommendations. Due to concern that the magnetic field of the coil used for powering the prosthesis could affect the electromyographic signal in the HIP98 dataset, we also compared our model-based activations to experimental electromyographic data available in the literature [16-19]. This process of scaling, inverse kinematics, inverse dynamics, static optimization, and joint reaction analysis was repeated for the model.

Result and Discussion

Musculoskeletal models allow us to investigate neuromuscular coordination, assess athletic performance, and calculate musculoskeletal loads. OpenSim is free and open-source software that allows users to create, visualize and analyze models of the musculoskeletal system as well as create dynamic movement simulations [1]. Researchers can also look into joint kinematics, musculoskeletal geometry, and muscle-tendon properties to see how they affect the joint moments and forces that muscles can generate. The objective of OpenSim is to provide a framework for researchers to create models and dynamic simulation tools for studying and quantifying human movement. The goal of this research is to study the relationship between muscle-tendon lengths and moment arms on limb models; find restrictions of musculoskeletal models; and study differences between bi-articular and uni-articular muscles. The goal of this research is to load a lower extremity model [2] into OpenSim and make it walk. The model depicts an adult subject standing 1.8 m tall and weighing 75 kg. The model is composed of 13 rigid body segments and 92 muscle action lines (43 per leg and 6 at the torso) Figure 1a. In OpenSim, muscle-tendon paths are represented by a series of points connected by line segments. Multiple lines of action are represented by the gluteus medius in this model. (e.g., glut_med1_r, glut_med2_r, glut_med3_r).

Examine how muscle-tendon lengths and moment arms vary according to limb models. Musculoskeletal geometry is critical to muscle function and the development of quantitative musculoskeletal models. Muscle-tendon forces are proportional to muscle-tendon length, and joint moments are proportional to both muscle-tendon forces and moment arms. As a result, accurate musculoskeletal geometry specification is critical in improving an accurate model for predicting joint moments and muscle-tendon forces. The Opensim Plotter displays muscle-tendon properties like length, force, joint moment, and moment arm.

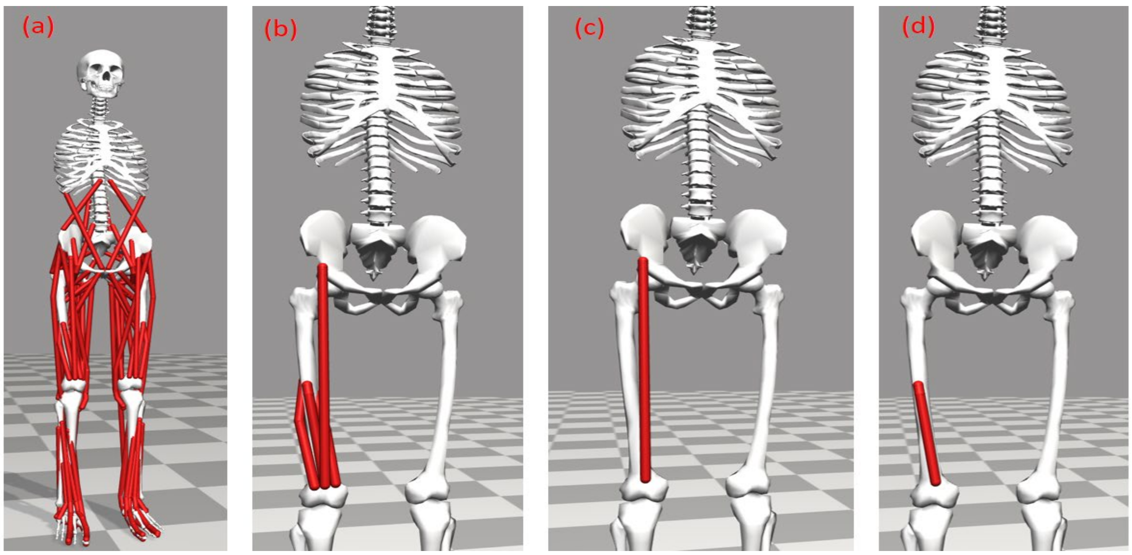

Figure 1: (a) graphical user interface (GUI), (b), (c) rectus femoris, and (d) vastus intermedius muscles

OpenSim software has been used to assess muscle fibre length changes. Fibre length was reported to be shortened during knee extension (Figure 2). This is the study to investigate effects of right hip extension angle on fiber lengths of rectus femoris muscle. It shows that the changes in hip extension angle, did not affect the fiber length of vastus intermedius muscle fibers (Figure 3).

Materials Research Proceedings 31 (2023) 187-193 https://doi.org/10.21741/9781644902592-20

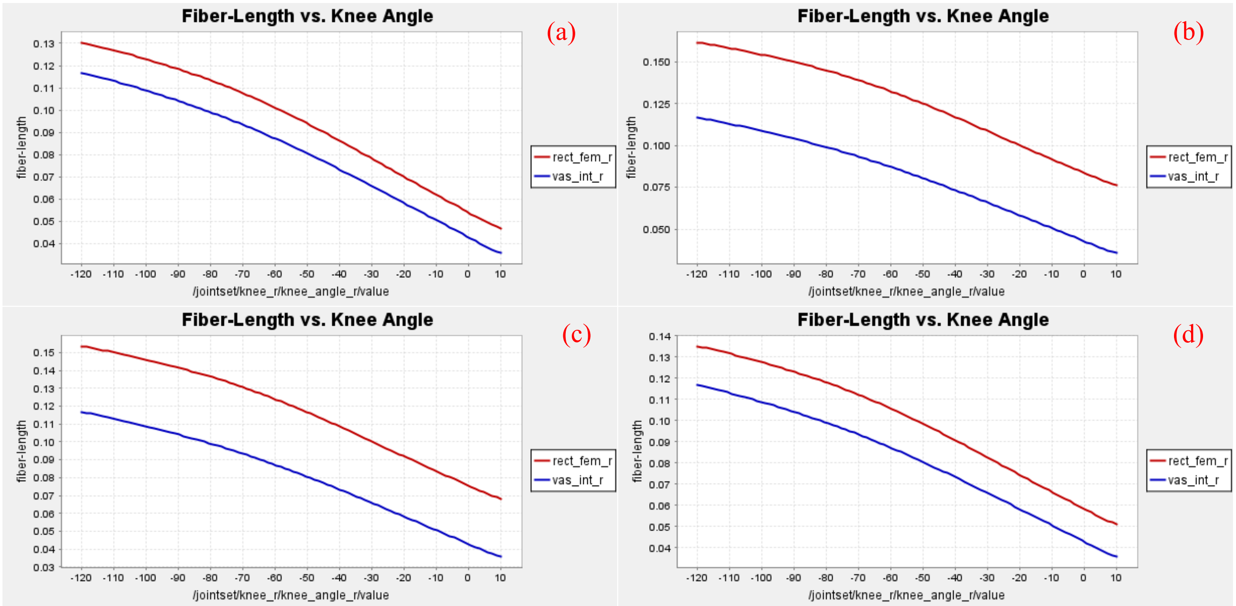

Figure 2: Fiber-Length vs. Knee Angle (right rectus femoris (rect_fem_r) and right vastus intermedius muscles (vas_int_r)) for right hip flexion to (a) 10, (b) 20, (c) 30, and (d) 40 degrees

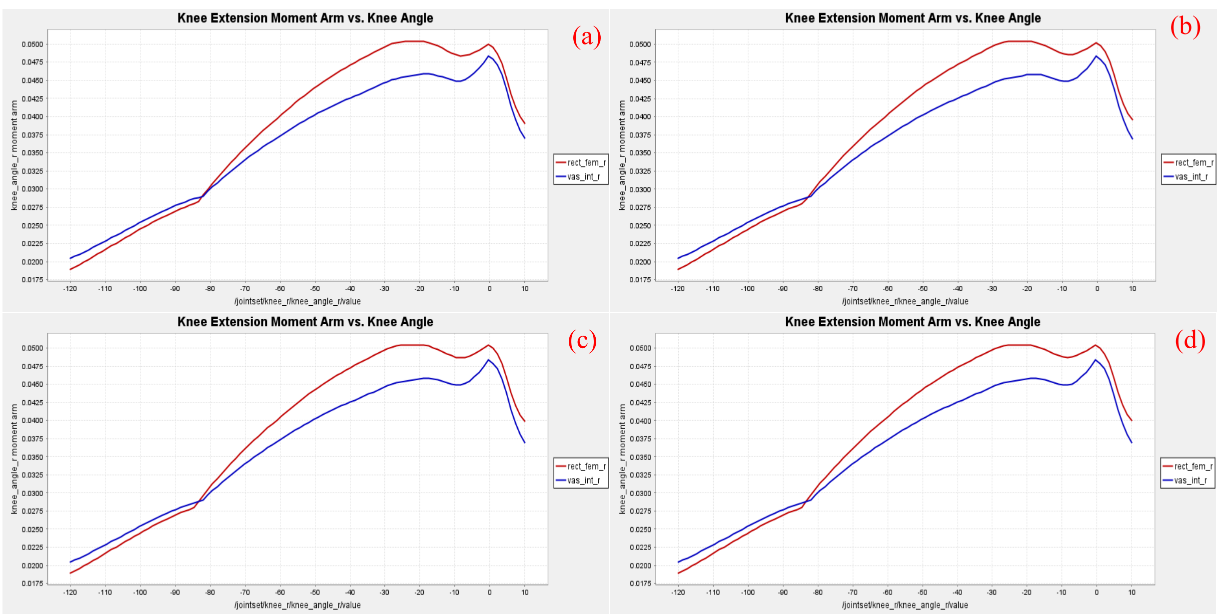

Figure 3: The knee extension moment arm vs. knee angle for the right rectus femoris and vastus intermedius muscles for right hip flexion to (a) 10, (b) 20, (c) 30, and (d) 40 degrees

Crouch gait is characterized by extreme knee flexion during the terminal swing and stance phases, making it one of the most common movement abnormalities in people with cerebral palsy. In many cases, abnormal hamstrings caused by spasticity [5-7] or static contracture [7, 8] are thought to be the cause of excessive knee flexion. Thus, surgical hamstring lengthening is commonly used to treat crouch gait, usually in conjunction with other orthopaedic procedures. Unfortunately, predicting which patients will benefit from hamstring surgery is difficult. OpenSim can predict which patients will benefit, change the speed, and rotate the models.

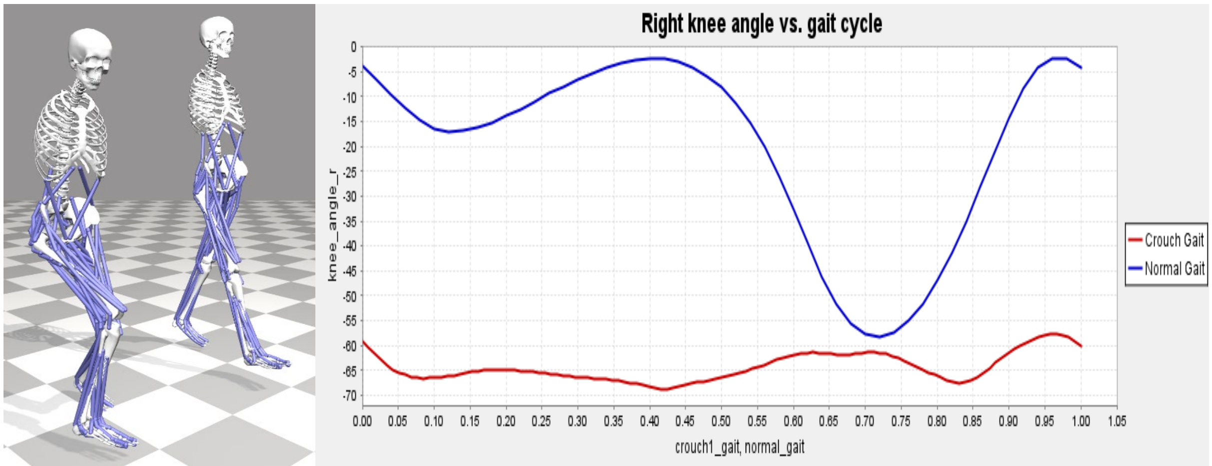

Figure 4: (a) Normal gait and crouch gait, and (b) Right knee angle vs gait cycle for normal gait and crouch gait.

Use OpenSim to study a possible cause of crouch gait, one of the most common walking abnormalities among people with cerebral palsy. It is distinguished by excessive knee flexion during the stance phase, which is frequently accompanied by exaggerated flexion and internal rotation of the hip. Short hamstrings are one of the hypothesized causes of crouch gait, and in order to improve a patient's gait, surgeons may lengthen the hamstrings. There could be other causes of excessive knee flexion. (e.g., weak ankle plantarflexors), and lengthening the hamstrings can impair these muscles' ability to generate force [3]. Develop a musculoskeletal model and compare the length of the hamstrings during the patient's crouch gait cycle to the length of the hamstrings during a normal gait cycle to determine whether a patient's hamstrings are shorter than normal Figure 4.

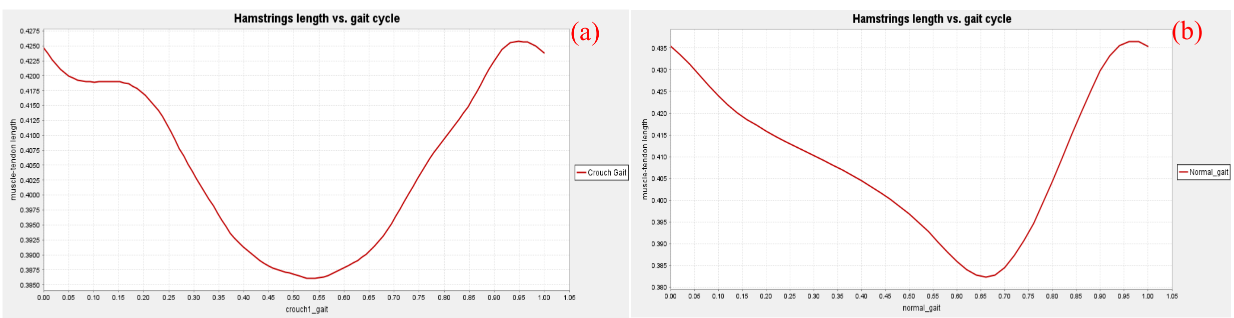

Figure 5: The length of the semitendinosus muscle-tendon during the (a) crouch and (b) gait cycles.

Figure 5 shows the length of the semitendinosus muscle-tendon over the crouch and gait cycles, compares the two motions, and describes the general differences in kinematics between the normal and crouch gait motions qualitatively. In addition, the length of the hamstrings during a patient's crouch gait cycle should be compared to the length of the hamstrings during a normal gait cycle.

Conclusion

In conclusion, the study developed a musculoskeletal full-body model. Despite some limitations, validation studies show that this model is suitable for predicting hamstrings length, muscle-tendon lengths, and muscle fiber length. When aiming at investigating hamstrings length, muscle-tendon lengths, and muscle fiber length, the model can serve as a basis for the normal and crouch gait models as well as for comparative purposes. In this study, the parameters and implementation choices of a generic musculoskeletal model have been modified. These include the number of degrees of freedom, the length and moment of the muscles, constraints, and the angle of the joints. As a result of these changes, the joint contact forces were more accurate than before, demonstrating that model predictions may be improved without the use of expensive and time-consuming medical tools. It was difficult to identify a trend defining which change had the greatest impact despite the high quality of the reviewed studies. In addition, there were discrepancies in the reported evidence about this impact.

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