Wheelchair Propulsion: Muscle Activity Analysis of Lower Extremity During the Gait

Some One

***Abstract*—Patients who use wheelchair to move forward may get accustomed to propel themselves using the their feet, which may lead to severe damage to their feet and bring problems for their recovery. Some researchers have been working on re-designing the wheelchair by changing the structure of wheelchair, adding some accessories and using novel rest for users. It's important for us to evaluate the possibility and availability for the new design. By combining the modelling in OpenSim and simulation in Matlab for muscles, we can full image about the overall tendency during the gait to check when and where is most constrained for muscles during the gait. We then analyze our outcome and simulation result and deliver some reflections on our project.**

Key words: Biomechanics, wheelchair, musculoskeletal modeling, OpenSim software.

I. Introduction

Wheelchair is deemed as basic orthopaedic equipment for the disabled people, weakened patients during recovery and the elderly people with increased mobility problems [1]. Proper operation way of wheelchair propulsion is of great significance for the recovery and recreation of patients suffering from diseases in orthopaedics [2]. However, Pieter van Foreest in Delft has found that wheelchair users still propel themselves with a limited degree, which may lead to the injury in their ankles by dragging the foot along.

Then it's very important to design some wheelchair mechanical accessories to solve this problem. Before going in-depth of design, a knowledge of motion and muscle activities makes it more straightforward to understand the effect of the aforementioned gait patterns.

It is apparent that muscle activities analysis is a very important research topic in wheelchair propulsion. In the context of wheelchair propulsion, wheelchair biomechanics mainly focuses on how users activate their power to the wheels to achieve the desired mobility [4]. Nearly ninety percent of wheelchair users worldwide prefer the push rim mode of propulsion for daily rehabilitation and mobility [5]. Consequently, the muscle analysis for upper extremity during the wheelchair propulsion has been widely studied. However, the overuse of muscles in the upper extremities and non-continuous push motions can lead to very severe injuries for wheelchair users [6]. Improved design such as new hand based wheelchair to release the stress upper extremity has also been put forward to prove that it is less straining to muscles than conventional wheelchair mode [7].

Besides the innovation in analysis of different design concepts, different types of tools could be implemented to study on those topics. Some studies utilize Microsoft Kinect to capture 3-dimensional imaging and to process skeleton position through real-time algorithms for some board motion applications [8] [9]. Some choose to use AnyBody, a musculoskeletal model simulation tool, to calculate the muscle activation in gait analysis [10]. Another more commonly-seen tool is the OpenSim where users can build and manipulate biomechanical models [11]. It can be used to simulate musculoskeletal dynamics and neuromuscular control. Its comprehensive abilities make it possible to handle different tasks ranging from discovering relationships between form and function that explain how humans move to model implantable and exoskeletal devices [11]. For example, Rankin and his colleagues constructed a musculoskeletal model of ostrich's lower limb and utilized an inverse approach in OpenSim to compute the muscle forces and work during walking and running [12]. They have found that biarticular muscles crossing both the hip and knee contribute most to propulsion during gait. Apart from musculoskeletal model construction, OpenSim also includes several inverse and forward solvers to calculate interest from a certain model. That makes it practical to apply OpenSim into our analysis method and process. Many models for similar topics regarding the wheelchair have been built by researchers, both upper and lower extremities are available that are applicable to the study of wheelchair propulsion biomechanics [13].

As stated before, upper extremity has been studied widely for normal gait on the wheelchair [14]. Nevertheless, studies

Fig. 1. A typical wheelchair real model for experiment. There are many types of wheelchair ranging from competition to medical assistance. The research field regarding the wheelchair also varies from the biomechanics analysis to multibody dynamics analysis for users [3]

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related to the muscle activities analysis of lower extremities are very limited, which has set obstacles for us to evaluate our new design concept. Under usual circumstances, the lower extremities are considered to be still or placed on the foot rest without moving.

That motivates us to focus on the muscle analysis for those wheelchair users who unconsciously propel themselves with a limited angle. We will analyze two main groups of wheelchair users with different gait behaviours on when driving the wheelchairs: one can move with two feet and another group can only move through one single foot. The main focus is located on which part of muscles in the lower extremity (especially region near the ankle) is the most strained for two different gait behaviours on the wheelchair. Other parameters including muscle forces, moment and generated mechanical work are also considered for our final analysis. The final outcome will provide a theoretical basis for evaluating or improving our wheelchair's accessory design in the future to see if it is effective or not.

II. Methods

We start by investigating how the musculoskeletal models can be simulated in OpenSim software. As stated before, this software provides us many possibilities to create different models for upper extremity, lower extremity and the whole body. For example, we present a very typical model as indicated in Figure 1. This model skeleton was built of 22 articulating rigid bodies, a pelvis and femur (left and right), patella, tibia/fibula, talus, calcaneus (including the tarsal and metatarsal bones), and toes to represent the lower body, and a combined head and torso and right and left humerus, ulna, radius, and hand to represent the upper body [15].

Besides the skeletal elements built in OpenSim, muscle tendon is also a very important factor to be considered during the modelling. The lower extremity model was actuated by around 80 muscle-tendon units in the lower body. There are 40 muscle-tendon units for each leg and 17 torque actuators (one for each degree of freedom in the upper extremity) which we don't have to give further analysis on their functionalities. Each muscle-tendon unit could be seen as mass-free which means the mass can be neglected considering our research topic and had a line of action approximating the path of the anatomical muscle volume from original initial point to be inserted [16]. The following picture shows how a three-dimensional model for the lower limb is.

After building all the models in OpenSim, by assigning different trajectories and constraints [17], we can utilized the inverse dynamics tool euqipped inside the OpenSim to evaluate the target muscle forces variation during the gait for normal stance and wheelchair-gait [18]. In order to double-demonstrate our result, we also finalize our experimental results by performing the skeletal and muscle analysis in Matlab through simple programming, what makes it complex is the characteristics of the muscles [19]. Each muscle-tendon unit was replaced with the Hill-type muscle model [20]. The force-generating capacity of each muscle-tendon unit was functioned using normalized fiber forceâlengthâvelocity and

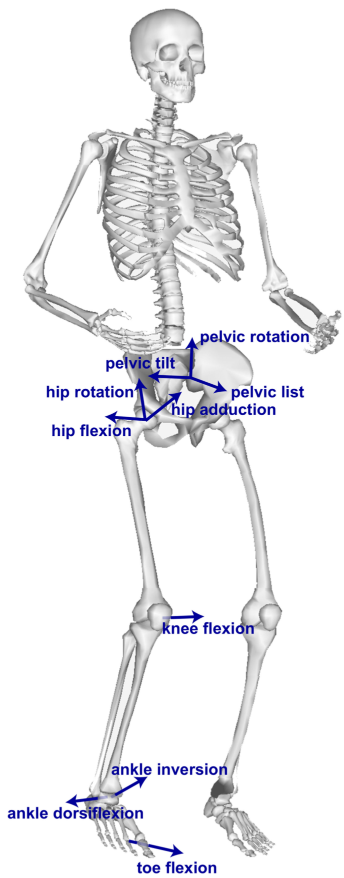

Fig. 2. Indication of Built Rigid bodies and degrees of freedom in the OpenSim model. The model was performed and indicated in OpenSim with around 22 rigid bodies representing the lower body (pelvis, and right and left femur, patella, tibia and fibula, talus, calcaneus, and toes and upper body. There were seven degrees of freedom in each lower limb (labeled for the right limb), three rotational and three translational (not labeled) degrees of freedom in the pelvis, and 17 degrees of freedom in the upper body (not labeled) [15]

tendon forceâlength curves which has been re-scaled for each muscle by a set of experimentally determined values for muscle maximum isometric force, optimal fiber length and other relevant parameters in musculoskeletal models [21].

By understanding the characteristics of muscles, we then start our simulation in Matlab through building the simple lower limb model. We don't stress too many staffs on multi-body dynamics during the gait, consequently, the main focus is about the activities for muscles, ankles and knees.

III. Results

We first present the result in Matlab by applying the computational characteristics of muscles into simple analysis. From the obtained tendency for both muscles and knees during a single-step gait. Therefore, we can see clearly about when the muscle force is the highest and when the angle of knees locates highest during the gait. These two are also very significant for us to give suggestion for patients and designers when evaluating the availability of new design.

IV. Discussion

According to the previously mentioned simulation result, we have found that the force at the initial stage during the gait

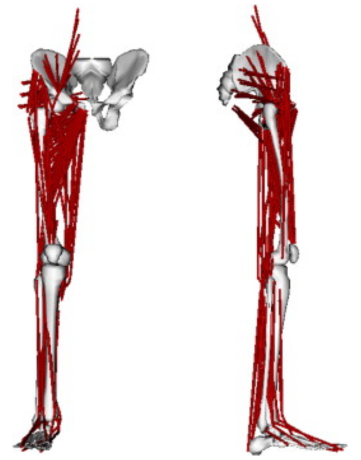

Fig. 3. Muscles were modeled as linear actuators in OpenSim. Muscleâtendon geometry used line segment paths restricted to initial point and insertion points

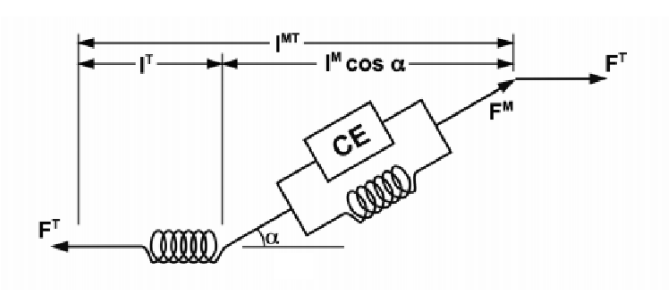

Fig. 4. Computational and simulated model of muscle-tendon units in both OpenSim and Matlab. Muscles were represented as massless linear actuators with active and passive properties described by quantified generic forceâlength and forceâvelocity curves [22]

has the largest magnitude for one single step, which means that the potential to be hurt during the movement. However, due to the capacity, it's impossible to simulate a wheelchair model in our project. Therefore, the result that we've presented is not visually vivid and the model is to some extent simple considering the limit of time. That's why we stress more on single piece of the whole model. From inspecting the activities of single part, it can still help us understand the overall situation. Besides the conditions we set for this simulation, We believe that our model can also be utilized to generate other primary simulations of unconventional walking and running gait on the wheelchair rather than the general movement.

V. Conclusion

The method of muscle-driven simulations are valuable tools for helping us understanding the role of muscles in healthy and pathological gait especially for people who needs the assistance from the external world, and can provide useful insights for assistive device design wheelchair-related assistance analysis [23]. Simulating and checking a model in the context of its intended use is an important step in any study using musculoskeletal modeling. We have introduced several demonstrating and validation of the model, including successful simulations of walking and running, but overall and full-side testing the community is needed [24]. The model is

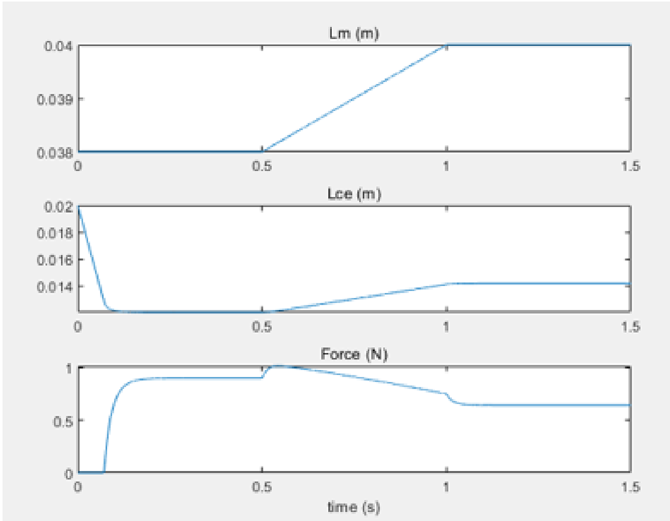

Fig. 5. Muscles activities variation during the gait for our model including the parameters of force and length

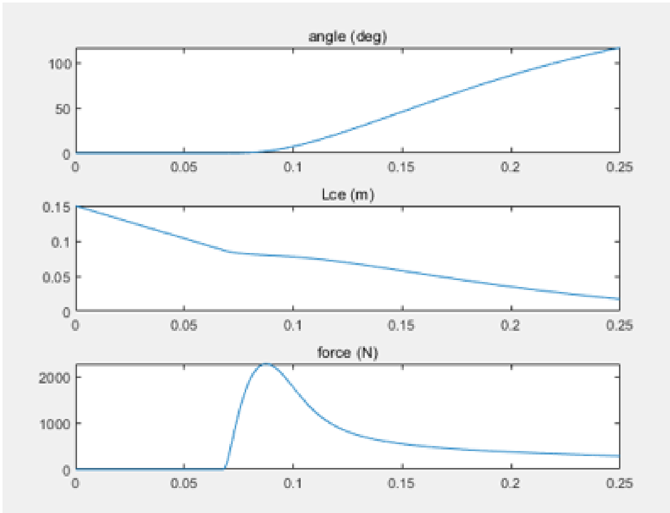

Fig. 6. Knees-relevant parameters variation during the gait for our model including the parameters of angle, length and force

freely accessible for use in OpenSim and Matlab for others to use and test.

Acknowledgments

Thank everyone who contributed with smaller pieces of advice or non-scientifically (e.g. technical support) especially for Professor Heike's assistance helping us get fully involved in this project with local medical community in Delft.

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