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Sensitivity of the anthropometrical and geometrical parameters of the bones and muscles on a musculoskeletal model of the lower limbs

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Abstract— **Modelling is necessary to understand and evaluate the musculoskeletal system of the human body. Most of the developed models used anthropometrical and geometrical parameters of the bones and muscles from the literature. The aim of the present work was to study the sensitivity of anthropometrical (segment mass) and geometrical (physiologic cross-sectional area of the muscle) parameters on musculoskeletal model of the lower limbs for simulation of the gait. An inverse dynamic analysis was performed to activate the joints and muscles. Then a direct dynamic analysis was carried out with active joints and muscles. The influences of these parameters on the kinematics and kinetics simulation results were reported. The obtained results show an influence of these parameters on the simulation results (maximal relative error varying from 2 to 75 %). These results suggest subject specific parameters to be considered.**

I. INTRODUCTION

The development of the musculoskeletal model is appropriate to simulate bone and joint pathologies such as rotational abnormalities of the lower limbs [1], clubfoot [2], and cerebral palsy [3]). Literature review shows two strategies of modelling. The first one concerns *home made* osteo-articular model or musculoskeletal model with sophisticated kinematics and dynamics formulations of the movement ([4]-[6]). The second one concerns musculoskeletal model with parameterized models, usually provided by specific software, such as SIMM [7], AnyBody [8],[9], and LifeMod ([10]-[12]).

The bones and muscles are biological structures used in the simulation of the human body. The personalization of these structures improves the reliability of the simulation results. But most of the developed models were parameterized, except for some models developed using SIMM software to study the cerebral palsy pathology [13]. Moreover, few clinical applications of these models are provided.

The anthropometric and geometrical parameters of the bones and muscles were obtained from literature. Data provided by Dempster and Gaughran, 1967 [14] and Zatsiorsky and Seluyanov, 1985 [15] were often used to calculate the body segment mass. Concerning the muscles, the values of pCSA (Physiologic Cross-Sectional Area) were also obtained from the literature. Besides, each study gives different orders of magnitude (Schumacher et Wolff, 1966 [16]; Horsman et al, 2007 [17]).

There are some studies of the sensitivity of the anthropometrical data on the kinematics and kinetics results ([18],[19]). But according to our knowledge, there is no study related to the sensitivity of the muscles parameters. Consequently, the objective of this study is to investigate how anthropometrical and geometrical parameters of the bones and muscles influence the kinematics and kinetics results of a musculoskeletal model of the lower limbs. The sensitivity of two parameters was studied: the body segment mass computed by 3 methods: Dempster et Gaughran, 1967; Zatsiorsky et Seluyanov, 1985; Yang, 2006 ([20]-[21]) and pCSA used from 3 methods: Schumacher et Wolff, 1966 [16]; Foidart-Dessalle, 2000 [22]; Horsman et al, 2007 [17].

II. METHODS

First of all, a musculoskeletal model of the lower limbs was developed. Anthropometrical parameters such as the mass percentage of each segment, the length, the circumference of body segments were measured on a healthy subject (male, 29 years old, 1m68, 65kg) to calculate body segment mass based on 3 methods. The Yang's method used the regression equations. The Dempster's method used anthropometric table extracted from cadaveric studies. The Zatsiorsky's method concerned anthropometric table extracted in vivo from a sportive young population (age: 24 ± 3).

Second, the musculoskeletal model was performed with the BGR.LifeMod (Msc. Software) software. On one hand, the segments (the pelvis, the left and right upper leg, the left and right lower leg, the left and right foot), joints (hip, knee, ankle), and muscle (10 significant muscles of the movement analysis of the lower limbs such as quadriceps, the soleus, etc.) were computed (Fig. 1). Then, the values of segment mass and pCSA were used. On the other hand, the default values were used for all other parameters (the biomechanics behavior, the stiffness, the damping, the maximal stress, etc.). The normal gait was simulated using the direct/inverse dynamics algorithms of the Lifemod software. The influences of these parameters on the kinematics and kinetics results were reported. The simulation scenario is illustrated in Fig.2.

The influences of the body mass and the pCSA were studied on 1) the joint angles 2) joint torques 3) the reaction forces 4) muscle forces. The relative error, which is defined by the difference between two values of the different curves

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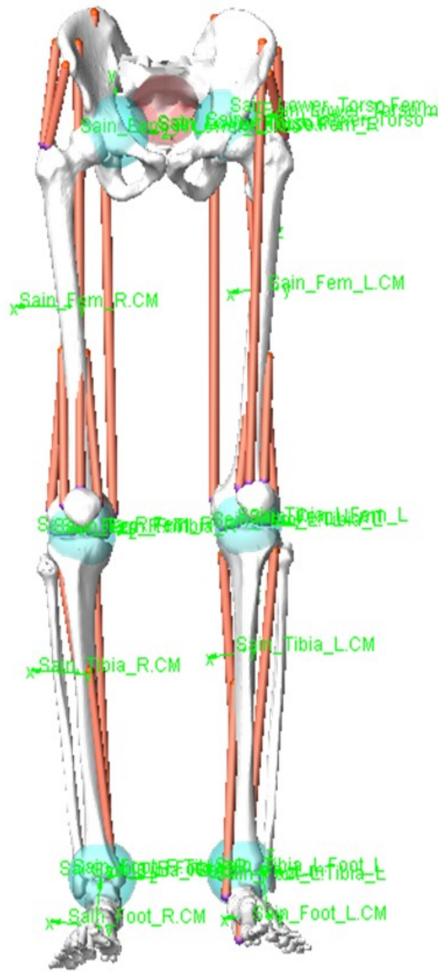

Fig. 1. Our developed musculoskeletal model

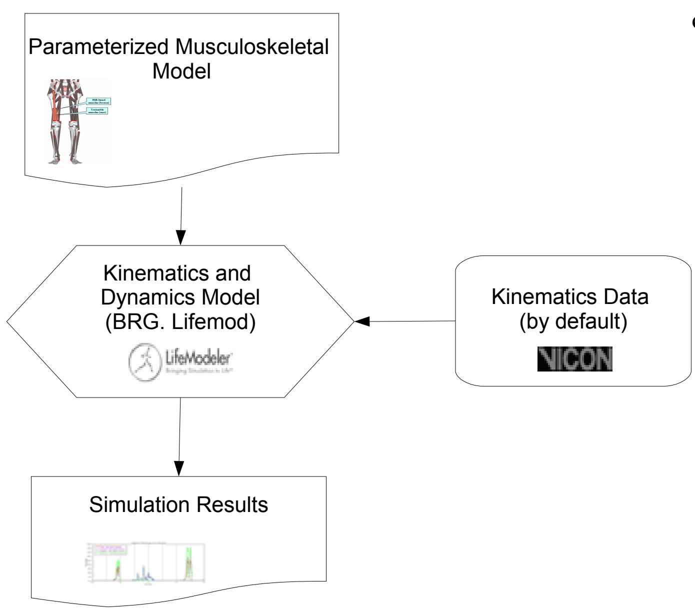

Fig. 2. Our simulation scenario

at the same time divided by the maximum of both values, was calculated during the gait cycle. This magnitude was used to perform the quantitative sensitivity analysis.

III. RESULTS

The kinematics and dynamics results of the simulation are presented below.

The influence of the segment mass on the joint angles is illustrated in Fig. 3. The maximal relative error found is around 4 % (mean value of the maximal relatif error of hip, knee, and ankle).

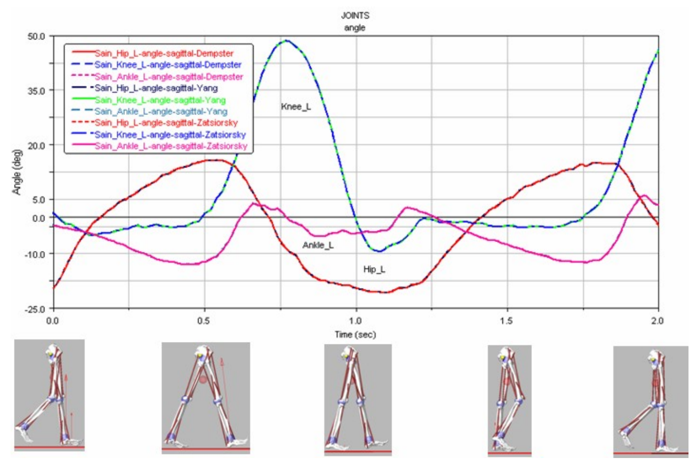

Fig. 3. Influence of the segment mass on the joint angles

The influence of the segment mass on the joint torques of the hip is illustrated in Fig.4. The maximal relative error between Dempster and Zatsiorsky methods is 18 %. However, the maximal relative error between the Yang and other methods is 74 %.

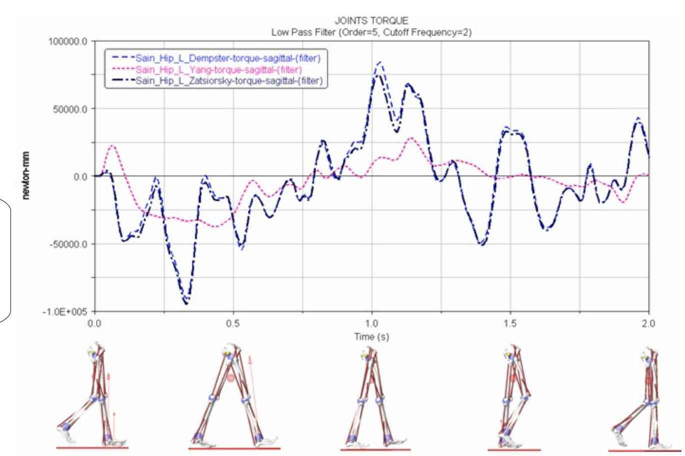

Fig. 4. Influence of the segment mass on the joint torques

The influence of the segment mass on the reaction forces is illustrated in Fig.5. The reaction force generated in the left foot is slightly different from that of the right foot. The maximal relative error between methods used is 20 %.

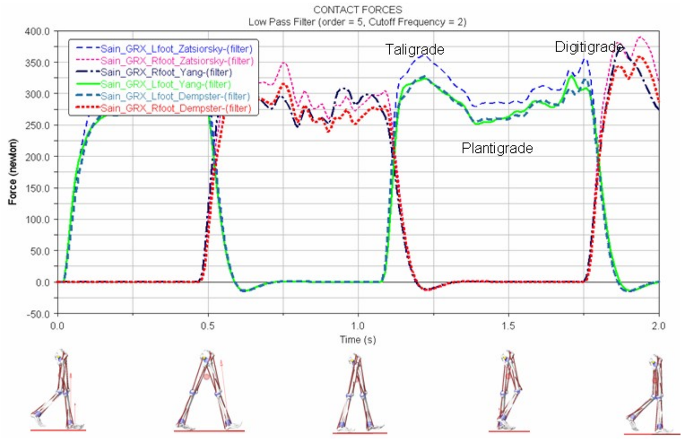

Fig. 5. Influence of the segment mass on the reaction forces

The influence of the segment mass on the muscle force of the soleus is illustrated in Fig.6. The maximal relative error between methods used is 29 %.

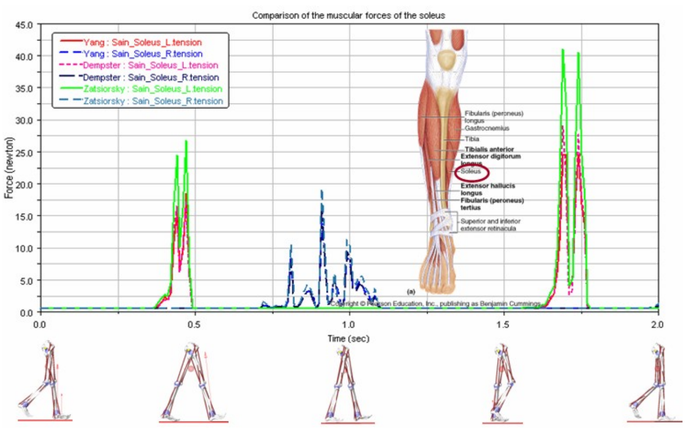

Fig. 6. Influence of the segment mass on the muscle force of the soleus

The influence of the pCSA on the joint angles is illustrated in Fig. 7. The maximal relative error between methods used is 2 %.

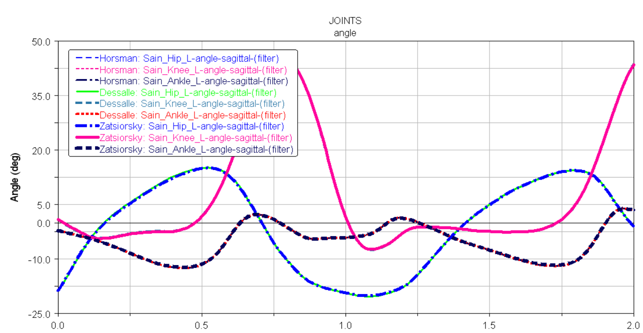

Fig. 7. Influence of pCSA on the joint angles

The influence of the pCSA on the joint torques of the hip is illustrated in Fig.8. The maximal relative error between methods used is 75 %.

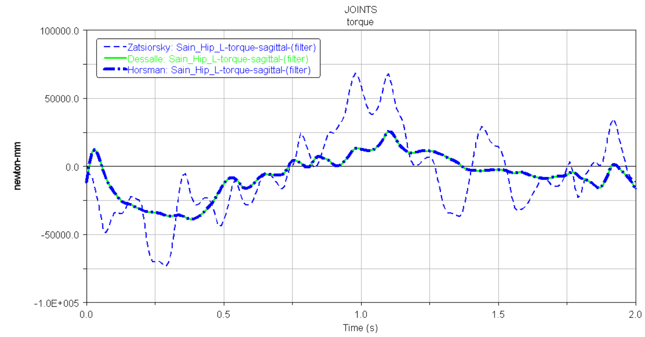

Fig. 8. Influence of pCSA on the joint torques

The influence of the pCSA on the reaction forces is illustrated in Fig.9. The maximal relative error between methods used is 12 %.

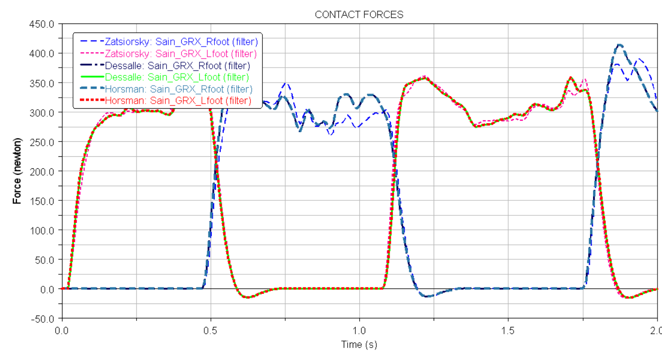

Fig. 9. Influence of pCSA on the ground reaction forces

The influence of the pCSA on the muscle force of the soleus is illustrated in Fig.10. The maximal relative error between methods used is 28 %.

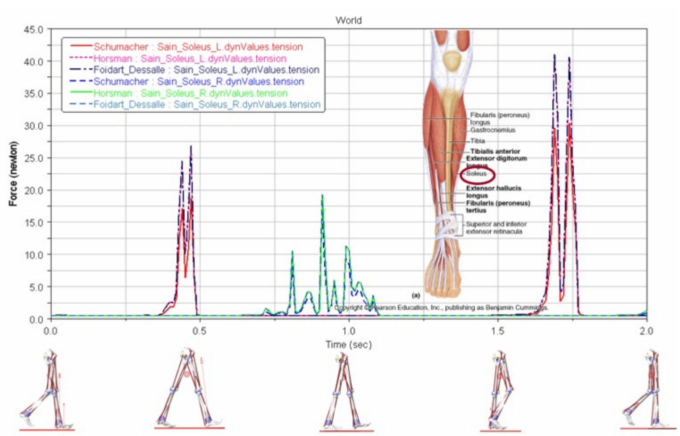

Fig. 10. Influence of pCSA on the muscle force of the soleus

IV. DISCUSSION

In our approach, the articular angles are not sensitive to the variation of the anthropometrical and geometrical parameters. This is explained by the fact that the same kinematics data were used as input data for all dynamic simulations. On the contrary, the joint torques are sensitive to the variation of the mass properties of the segments and the physiologic cross-sectional area of the muscles. Moreover, the results of the Yang method are widely different from other methods (Dempster and Zatsiorsky).

The difference in reaction forces and muscle forces can be explained by the difference of physiologic cross-sectional areas pCSAs. One should note that the more pCSAs are large, the more muscular forces are significant.

Our observations strengthen the debates ([19],[25]) on the strong influence of BSIP (Body Segment Inertial Parameter) on the kinematic and kinetic parameters of motion analysis. Furthermore, the strong impact of the pCSA parameter on the kinematics and kinetics results should be considered for the development of the musculoskeletal models.

V. CONCLUSIONS AND FUTURE WORKS

A study of the sensitivity of anthropometrical and geometrical parameters of the bones and muscles was carried out on a musculoskeletal model of the lower limbs. The obtained results show a strong impact of these parameters on the simulation. So, subject specific parameters should be considered when performing musculoskeletal model. In perspectives, the experimental measurements are to be performed to obtain the subject specific anthropometrical and geometrical parameters of the bones and muscles. Then, these data could be used to simulate the gait of healthy subjects for reference database and pathological locomotor subjects (cerebral palsy, Heine-Medin, Polio, etc.) for the diagnosis and surgery planning.

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