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Muscles force and joints load simulation of bicycle riding using multibody models

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Abstract

A three dimensional multibody dynamic numerical model using LifeMOD and ADAMS is presented to simulate and analyze the load of wrists, shoulders, leg muscles, knees, and ankles of bicycle riding. Applications of ADAMS/LifeMOD are widely used, for example, rifle shot stress to the human body, golf swing, Tae Kwon Do side kick simulation, rowers paddle boat. Applications are even in the medical research including dynamic stability of human spine simulation, and thoracic and lumbar dynamic simulation. Vertical (height) and horizontal position of bicycle saddle are adjusted in the three dimensional multibody model to simulate muscles force for city bicycle riding and race bicycle riding. Besides, loads of shoulders, wrists, knees, and ankles are analyzed between postures of city bicycle riding and race bicycle riding. The objective of this research is to obtain a suitable posture either for city bicycle riding or race bicycle riding to prevent sports injuries. ADAMS/LifeMOD simulation of riding city bicycle and race bicycle with different riding postures is presented in this paper. Several main findings include: (1) If the bicycle saddle is too high, soleus force would be increased. (2) If the bicycle saddle is too low, biceps femoris and iliacus forces would be increased. (3) The influence on muscles force caused by a little adjustment of distance between saddle and handlebars may be ignored. (4) Posture of riding race bicycle bends upper body more and increases iliacus forces but decreases soleus force. (5) Because race bicycle riding posture bends upper body, the joints loads on lumbar, shoulders and elbows are greatly increased.

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Keywords: Multibody; bicycle; LifeMOD; ADAMS

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1. Introduction

Research on human body motion includes experimental measurement and dynamic analysis. Experimental measurement, such as Vicon® system developed by Oxford Metrics Group, attaches marks to the joints of human body to be measured and then high-speed camera is used to video human motions. Image analysis is used to obtain speeds and accelerations of human body motions from the information videoed. However, the experiment method needs very expensive equipments and requires a large space. Dynamic analysis on the human body motion has been motivated by the advanced computational ability and excellent graphical display capability of modern computers. Computer software ADAMS/LifeMOD are widely used in analyzing human body motion. For example, it is used to study the rifle shot reaction on human body [1], to simulate golf driving [2] and modelling boat rower [3]. LifeMOD/ADAMS are even used in the medical research to study dynamics of thoracolumbar spine [4]. On bicycle riding simulation, Waechter *et al.* built a multibody model to study bicycle suspension system [5]. Wang and Hull built a dynamic system model for bicycle riding [6]. Both of these studies model the human body by two-dimensional lumped masses system without detailed modeling of muscles and joints. A three-dimensional multibody dynamic numerical model built by using LifeMOD/ADAMS is presented in this paper to simulate and analyze the muscles force and joints load of human body on bicycle riding. The results of this research may be used to obtain a suitable posture either for city bicycle riding or race bicycle riding to improve bicycle pedalling forces and prevent sports injures.

2. Methods

ADAMS is a multibody dynamics software developed by MDI (Mechanical Dynamics, Inc.). It can be used in a complex mechanical system to create "virtual machine." This virtual machine can be used to simulate mechanical systems dynamically to analyze the kinematic and dynamic problems. LifeMOD is a three-dimensional computer model of human body developed by LifeModeler, Inc. This model consists of 19 segments for skeleton which are connected by 18 joints (Figure 1(a)). Muscles are modelled by spring-damper complexes (Figure 1(b)). LifeMOD contains a database for the spring stiffness and damping coefficient based on input parameters (ht, wt, etc.). Integration of LifeMOD and ADAMS can be used to analyze motions and forces of human body.

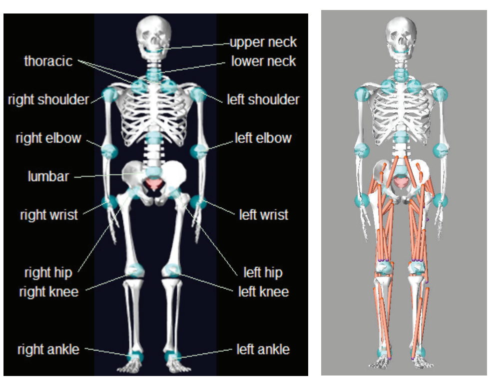

Fig. 1. (a) LifeMOD segments and joints; (b) LifeMOD muscles system (red lines) [7]

In this research, a male subject with 171.5 cm height and 62 kg weight is modeled for riding a city bicycle and a race bicycle. ADAMS/LifeMOD is employed to solve the muscles force and joints load.

The three-dimensional bicycle model is composed of front and rear wheels, handle bars, fork, saddle, saddle post, bicycle frame, pedals, and sprocket. The human body model is then adjusted by bring up LifeMOD posture panel and inputting relative joint angles so that the model would fit the city bicycle and race bicycle riding posture respectively (Figure 2). Bushing joints were used to link hands, hip and feet with handles, saddle and pedals respectively. Bushing joints have the same stiffness and damping as muscles.

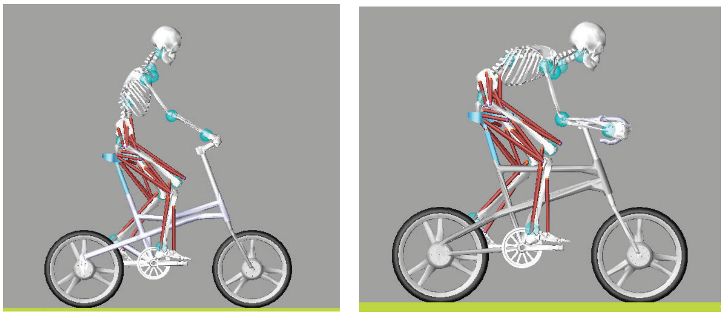

Fig. 2. (a) City bicycle model; (b) race bicycle model

Muscles examined in this research include adductor magnus, biceps femoris, gluteus maximus, vastus medialis, vastus lateralis, rectus femoris, semitendinosus, soleus, gastrocnemius, tibialis anterior, iliacus and psoas major which are modelled by spring-damper complexes. Lower body joints including ankles, knees and hips are set up as passive stiffness joints in LifeMOD. The stiffness of passive joints will then record from an inverse dynamic analysis. Upper body joints examined including lumbar, shoulders and elbows are strength joints which have the same joint properties as Hybrid III dummy.

After setting up the human model with LifeMOD, an inverse dynamic simulation of bicycle riding will be done by ADAMS. During inverse dynamic simulation, a motion driver is equipped at the bicycle crank and makes the bicycle pedalling itself. The legs of human body are therefore driven by the crank through pedals. The spring-damper complexes (muscles) contraction histories will be recorded in inverse dynamic simulation. Then the motion driver will be removed and the muscle contraction histories are employed to perform a forward dynamic simulation. During forward dynamic simulation, the bicycle will be pedalled by human model to recreate the motion history and show the relationship between muscles force and bicycle motion. Several bicycle riding postures are simulated to evaluate muscles force and joints loads, and the results are discussed in the following section.

3. Results and Discussion

Standard saddle position is defined according to the following conditions: (a) With the heel steps on the centre of the paddle, the thigh and leg are just stretch out. (b)With the crank in horizontal, the knee and tiptoe are on a vertical line (Figure 3).

Fig. 3. Standard saddle position

Figure 4(a) shows muscles force (in Newton) corresponding to the crank position in polar coordinates when human model is riding city bicycle at 60 rpm with the standard saddle position. The results show that soleus, biceps femoris and iliacus contribute the major pedalling forces. Soleus force is over 600 N at 130° crank angle, biceps femoris force is over 400 N at 280° crank angle and iliacus force is about 600 N at 320° crank angle to raise the hip. Figure 4(b) shows the percentage of muscles force in above simulation.

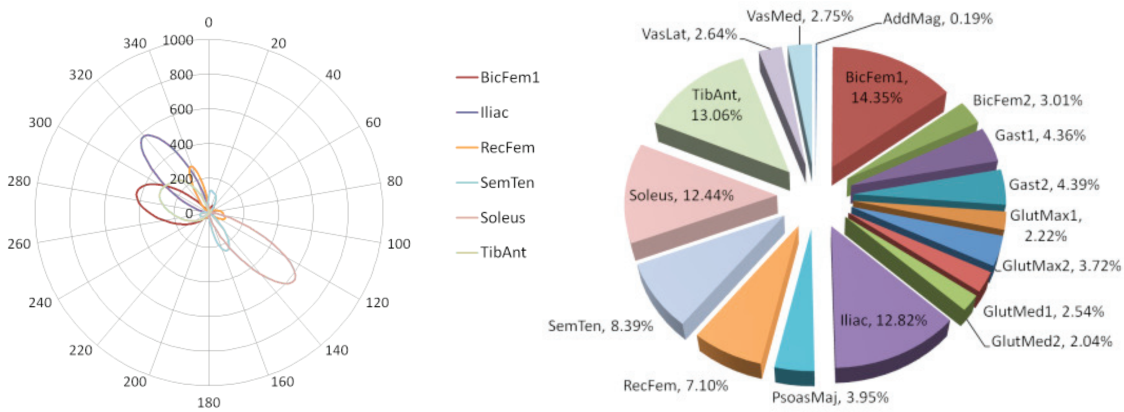

Fig. 4. (a) Muscles force vs. crank position for riding city bicycle; (b) percentage of muscles force for riding city bicycle

Figures 5(a) and 5(b) show the percentage of muscles force with city bicycle saddle being adjusted 3 cm higher and 3 cm lower, respectively, than the standard position. Comparing Figure 5(a) to Figure 4(b) shows that noticeable variations are soleus force increased but biceps femoris and iliacus forces decreased when saddle is higher. However Figure 5(b) shows opposite results when saddle is lower.

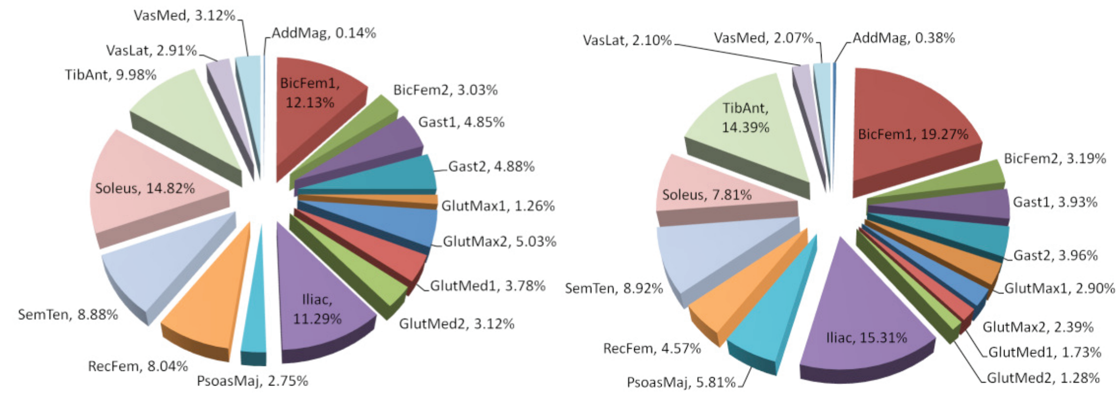

Fig. 5. (a) percentage of muscles force for saddle 3 cm higher than the standard position; (b) percentage of muscles force for saddle 3 cm lower than the standard position.

Figures 6(a) and 6(b) show the percentage of muscles force with city bicycle saddle being adjusted 3 cm toward and 3 cm backward from the standard position, respectively. In general, the percentage of muscles force do not have much difference by comparing Figure 6(a) and 6(b) with respect to Figure 4(b).

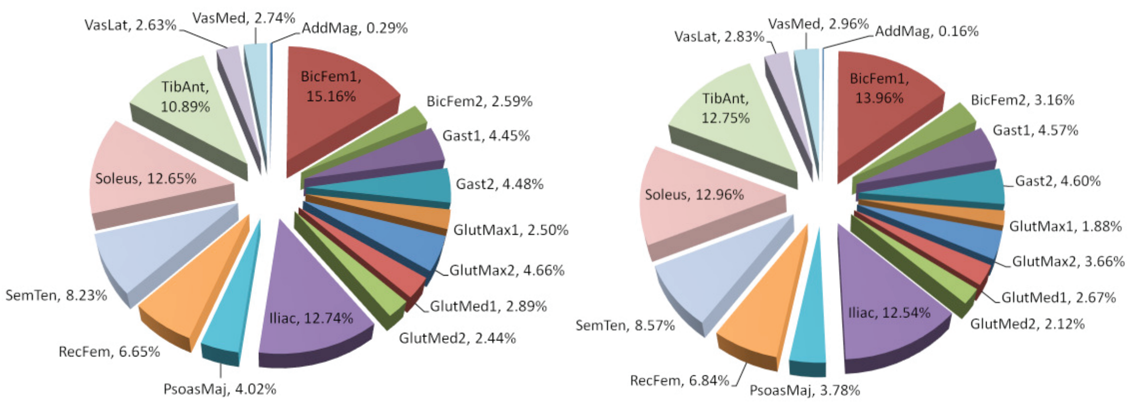

Fig. 6. (a) Percentage of muscles force for saddle moved 3 cm forward from standard position; (b) percentage of muscles force for saddle moved 3 cm backward from standard position

Figure 7(a) shows muscles force corresponding to the crank position in polar coordinates, and Figure 7(b) shows the percentage of muscles force when human model is riding race bicycle at 60 rpm with the standard saddle position. Noticeable variations of riding race bicycle are soleus force decreased and iliacus forces increased (Figure 7) compared with riding city bicycle (Figure 4).

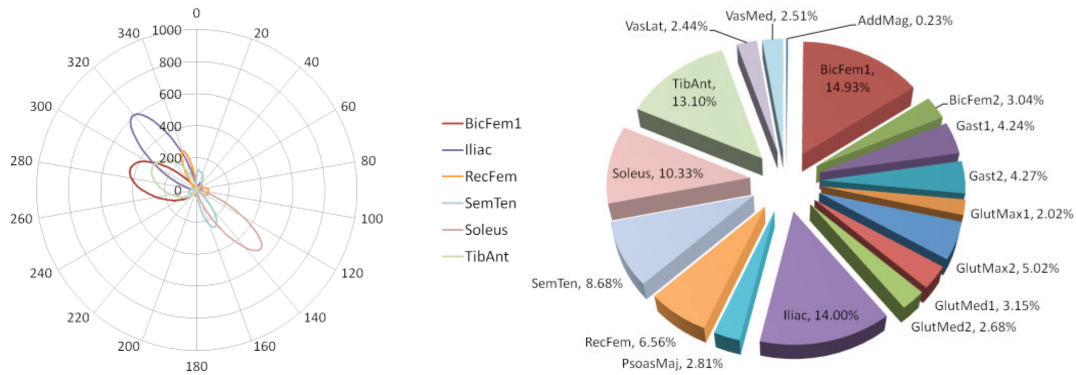

Fig. 7. (a) Muscles force vs. crank position for riding race bicycle; (b) percentage of muscles force for riding race bicycle

Comparison of joints torque and force between riding city bicycle and race bicycle are shown in Figure 8 and Figure 9. Torque on lumbar due to riding race bicycle is 176.36% compared with that of riding city bicycle (Figure 8). Force on shoulder and elbow due to riding race bicycle are 423.48% and 354.0%, respectively, compared with that of riding city bicycle (Figure 9). Other joints load don't have much difference.

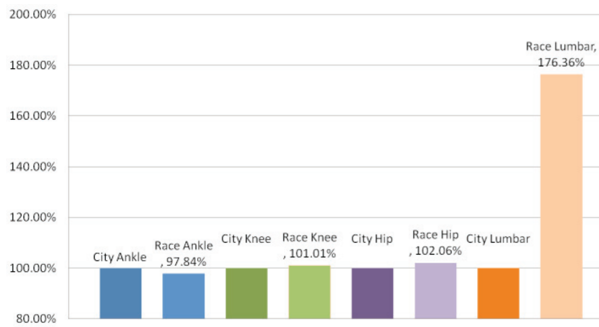

Fig. 8. Comparisons of torque on joints for race bicycle riding vs. city bicycle riding

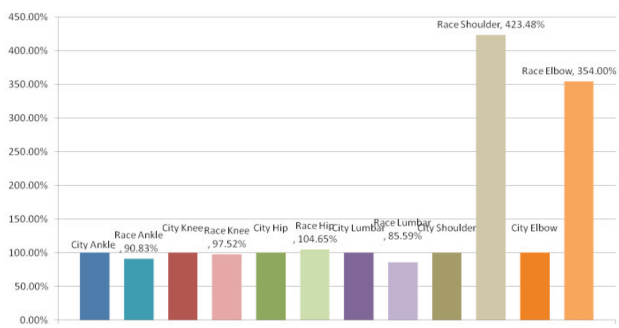

Fig. 9. Comparisons of force on joints for race bicycle riding to city bicycle riding

4. Conclusions

ADAMS/LifeMOD simulation of riding city bicycle and race bicycle with different riding postures is presented in this paper. Several main findings include: (1) If the bicycle saddle is too high, soleus force would be increased. (2) If the bicycle saddle is too low, biceps femoris and iliacus forces would be increased. (3) The influence on muscles force caused by a little adjustment of distance between saddle and handlebars may be ignored. (4) Posture of riding race bicycle bends upper body more and increases iliacus forces but decreases soleus force. (5) Because race bicycle riding posture bends upper body, the joints loads on lumbar, shoulders and elbows are greatly increased.

Acknowledgements

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