Proceedings of the 17th Iranian Conference of Biomedical Engineering (ICBME2010), 3-4 November 2010

Comparison of Passive and Active Prosthetic knee Joint Kinematics during Swing Phase of Gait

Y. Dabiri[1], S. Najarian[2], M. R. Eslami[3], S. Zahedi[4], H. Farahpour[5], R. Moradihaghighat[6]

[1]Faculty of Biomedical Engineering, Amirkabir University of Technology, Tehran, Iran, Ydabiri@gmail.com
[2]Full-Professor of Biomedical Engineering, Faculty of Biomedical Engineering, Amirkabir University of Technology, najarian@aut.ac.ir *Corresponding Author
[3]Full-Professor of Mechanical Engineering, Faculty of Mechanical Engineering, Amirkabir University of Technology, eslami@aut.ac.ir
[4]University of Surrey,Guilford, UK, SaeedZ@blatchford.co.uk
[5]Janbazan Medical and Engineering Research Center (JMERC), Tehran, Iran, hamed_farahpour@yahoo.com
[6]Faculty of Biomedical Engineering, Amirkabir University of Technology, Tehran, Iran, reyhane.moradihaghighat@gmail.com

Abstract*— The goal of this paper was to assess this hypothesis that a powered prosthetic knee, to which net power is delivered, is capable of emulating the swing phase of the biological knee better than an energetically passive knee. Lower extremity was modeled as a two-degree of freedom linkage, for which hip and knee were joints. Based on an inverse dynamics approach, computer simulations were carried out to calculate both active and passive prosthetic knee angles during swing phase of gait. Results showed that since an active prosthetic knee can deliver power, it can mimic the normal knee flexion angle better than a passive one. Consequently, it can lead to a more symmetric, and therefore, more efficient gait.

Keywords-prosthetic knee joint; simulation; swing phase of gait

I. INTRODUCTION

Amputation of the lower extremity, specifically at the transfemoral level, is one of the main sources of disability. Limb loss affects approximately 1.9 million people in the United States, 400,000 of whom have amputations above the knee [4]. After above the knee amputation, a prosthetic leg which mainly includes a socket, knee, shank and foot is routinely prescribed. The prosthetic knee requires the highest degree of control for safe ambulation [3].

Current commercial prosthetic knees are passive i.e. they are not capable of generating net power. This prevents the prosthetic knee from emulating the normal angle of the biological one, and leads to an asymmetric gait which contributes to higher energy expenditure of transfemoral amputee gait in comparison to the healthy subjects' gait [12]. Furthermore, it may lead to spine and lumbar deterioration [11].

It is speculated that a powered prosthetic knee is able to address the deficiencies of the passive knee joints [13]. Although no published literature exists, Ossur, a major prosthetics company based in Iceland, has announced the development of a powered prosthetic knee [13], and research is on the way to design and construct prosthetic knees that are capable of generating power (For example, [5] and [13]). Yet, due to the inability of current technology to mimic the ability of biological muscles to produce a large amount of force in a small volume, design and construction of those knees will be a difficult task [5].

On the other hand, for normal walking, it is shown that the role of muscles during the swing phase of gait is not important as during the stance phase. Some studies suggest that the forces exerted by muscles in the swing phase may be neglected. For example, Mochon and McMahon [8] found a range of initial segment angular velocities that could achieve toe clearance without the action of muscles. Also, Mena et al. [6] found that without including moments applied by muscles, a near- normal swing can be simulated. McGeer [7] analyzed and built two- legged passive dynamic machines with knees that could walk down slight slopes without the activities of muscles.

Consequently, it is possible that a prosthetic knee that is capable of delivering power will not have a noticeable effect on the swing phase of prosthetic leg.

In this study, based on an inverse dynamics approach, computer simulation was used to compare the passive and active prosthetic knee kinematics, to quantitatively assess this hypothesis that an active prosthetic knee, capable of delivering net power, will mimic the flexion angle of the biological knee better than an energetically passive one.

II. MATERIALS AND METODS

Two models of the lower extremity were studied. In both models, the lower extremity was modeled as a two-degree of freedom pendulum, for which, the hip and knee were joints. The residual limb included some muscles shown in Fig. 1 and 2. As the first model, the passive prosthetic knee, using MSC ADAMS software, was modeled as a hinge joint with a damper and a spring (Fig. 1). In the second model, using MATLAB software, the active prosthetic knee joint was included, for

978-1-4244-7484-4/10/$26.00

which a pair of virtual antagonist muscles delivered power (Fig. 2).

The normal hip and knee angles were inputs to the models [9], and the torques at these joints were calculated to produce the desired input angles. For the first model, an optimization analysis was carried out, through least square method, to calculate the values of knee stiffness and damping. For the second model, the forces of the antagonist muscles were calculated to produce the desired knee angle [2]. The governing equation of the models is [10]:

$$\begin{bmatrix} \ddot{\theta}_H \\ -\ddot{\theta}_K \end{bmatrix} = M^{-1}C\begin{bmatrix} \dot{\theta}_H^2 \\ \dot{\theta}_K^2 \end{bmatrix} + M^{-1}V\begin{bmatrix} -\dot{\theta}_H\dot{\theta}_K \\ 0.0 \end{bmatrix} + M^{-1}G + M^{-1}\begin{bmatrix} M_H \\ -M_K \end{bmatrix}$$

where $\ddot{\theta}_H$ and $\ddot{\theta}_K$ are hip and shank rotational accelerations, M, C, V, P and G depend upon joint angles and inertial parameters. M_H is the torque resulted from muscle forces about hip joint, and M_K is the torque about knee joint. In the passive model M_K is resulted from the damper and spring forces, and in the active model it is produced by the virtual muscles that span the knee.

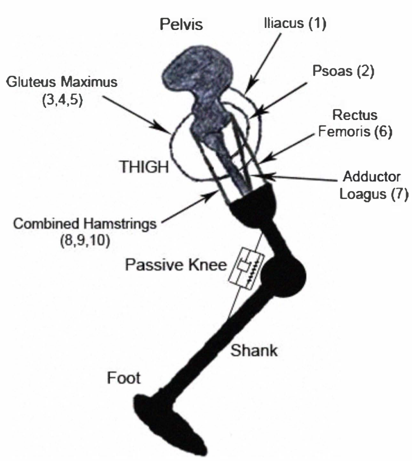

Figure 1. Schematic of the lower extremity with passive prosthetic knee.

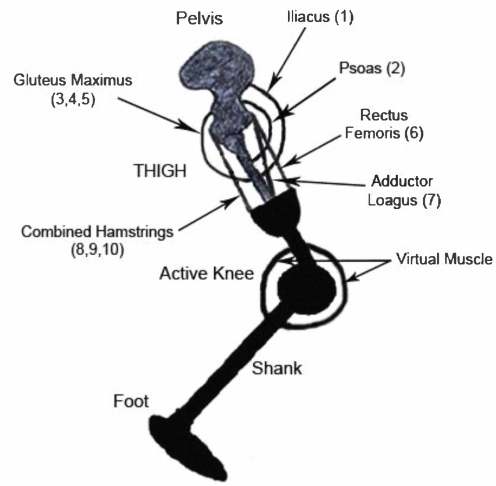

Figure 2. Schematic of the prosthetic leg with an active prosthetic knee. The knee has a pair of antagonist muscles that deliver power.

III. RESULTS

The knee angle during swing phase of a gait cycle is shown in Fig. 3 for both models and also biological knee. As this figure shows, in contrast to a passive knee prosthesis, an active one can track the biological knee angle. However, the passive knee flexion angle is near to the biological one. As reported by Anderson et al. [1], during the swing phase Coriolis, centrifugal, and gravitational forces, toe-off kinematics, and muscular forces affect knee flexion angle. Among these effects, the toe- off kinematics plays the main role in knee kinematics. In accord to the finding of Anderson et al. [1] and other studies that found without muscles a near-normal flexion maybe produced [6- 8], our results suggest that a passive prosthetic knee joint can produce a knee flexion angle near to that of the normal one. However, from Fig. 3 it is clear that a powered prosthetic knee is capable of emulating the biological knee angle much better than a passive one. So, it can lead to a more symmetric gait, and therefore, a more efficient gait will be obtained [12].

IV. CONCLUSIONS

In this paper the ability of a prosthetic powered knee joint to emulate the biological knee flexion, was compared with that of a passive prosthetic knee. According to the results, a powered prosthetic knee joint is capable of mimicking the biological knee angle better than a passive one. So, an active prosthetic knee will be able to accomplish a more symmetric walking, and therefore, more energy efficient gait.

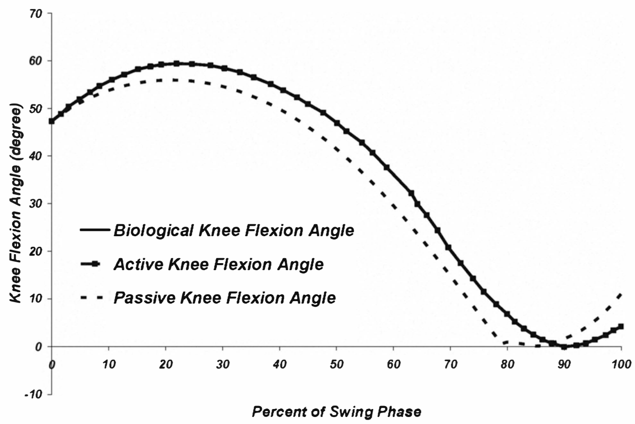

Figure 3. Biological (desired), active and passive knee flexion angles, during swing phase.

REFERENCES

[1] F. C. Anderson, S. R. Goldberg, M. G. Pandy, S. L. Delp, "Contributions of muscle forces and toe-off kinematics to peak knee flexion during the swing phase of normal gait: an induced position analysis," Journal of Biomechanics, 37, 731–737, 2004.

[2] Y. Dabiri, S. Najarian, S. Zahedi, D. Moser, E. Shirzad, " Muscle Contributions in the Swing Phase of Transfemoral Amputee Gait: An Inverse Dynamics Approach," Research Journal of Biological Sciences, 4, 1076- 1084, 2009.

[3] B. J. Hafner, L. L. Willingham, N. C. Buell, K. J. Allyn, D. G. Smith, "Evaluation of function, performance, and preference as transfemoral amputees transition from mechanical to microprocessor control of the prosthetic knee," Archives of Physical Medicine and Rehabilitation, 88, 207-17, 2007.

[4] K. R. Kaufman, J. A. Levine, R. H. Brey, Sh. K. McCrady, D. J. Padgett, M. J. Joyner, "Energy Expenditure and Activity of Transfemoral Amputees Using Mechanical and Microprocessor-Controlled Prosthetic Knees," Archives of Physical Medicine and Rehabilitation, 89, 1380-1385, 2008..

[5] E. C. Martinez-Villalpando, H. Herr, "Agonist-antagonist active knee prosthesis: A preliminary study in level-ground walking," Journal of Rehabilitation Research & Development, 46, 3, 361–374, 2009.

[6] D. Mena, J. M. Mansour, and S. R. Simon, "Analysis and synthesis of human swing leg motion during gait and its clinical applications," Journal of Biomechanics, 14, 823- 832, 1981.

[7] T. McGeer, "Passive dynamic walking," International Journal of Robotics Research, 9, 62- 82, 1990.

[8] S. Mochon, and T. A. McMahon, "Ballistic walking," Journal of Biomechanics, 13, 49- 57, 1980.

[9] J. Perry, "Gait Analysis," SLACK, Thorofare, NJ, 1992.

[10] S. J. Piazza, S. L. Delp, "The influence of muscles on knee flexion during the swing phase of gait," Journal of Biomechanics, 29, 723-733, 1992.

[11] D. J. Sanderson, Ph. E. Martin, "Lower extremity kinematic and kinetic adaptations in unilateral below-knee amputees during walking," Gait and Posture, 6, 126- 136, 1996.

[12] A. D. Segal, M. S. Orendurff, Klute, K. Glenn, M. L. McDowell, J. A. Pecoraro, Shofer, Jane, J. M. Czerniecki, "Kinematic and kinetic comparisons of transfemoral amputee gait using C-Leg® and Mauch SNS® prosthetic knees," Journal of Rehabilitation Research & Development, 43, 857–870, 2006.

[13] F. Sup, A. Bohara, and M. Goldfarb, "Design and control of a powered transfemoral prosthesis," The International Journal of Robotics Research, 27, 263- 273, 2008.