VERTICAL STIFFNESS DURING MAXIMAL SPRINTING IN A TRANSFEMORAL AMPUTEE: A CASE STUDY

Yoko Sano[1,2], Hiroaki Hobara[1], Wolfgang Potthast[3], Ralf Müller[3], Johannes Funken[3], Thijs A Heldoorn[1], Masaaki Mochimaru[1], Hiroshi Takemura[2]

National Institute of AIST, Tokyo, Japan[1]
Tokyo University of Science, Chiba, Japan[2]
German Sport University Köln, Köln, Germany[3]

Running-specific prostheses emulate the spring-like behaviour of biological limbs during human running, but little is known about the spring-like leg functions in transfemoral amputees. Understanding of running mechanics is expected to benefit the design of prostheses and to prevent injuries. The purpose of this study was to clarify the spring-like behaviour of sprinters with transfemoral amputations using running specific prosthesis. The vertical stiffness was calculated using a spring-mass model. The vertical stiffness in prosthetic limbs tends to be greater than in intact limbs for transfemoral amputees.

KEY WORDS: prosthetic sprinting, leg spring, spring-mass model.

INTRODUCTION: Recently, athletes with lower extremity amputations have achieved remarkable sprint performances using running-specific prostheses (RSPs). In running, the whole body is often modelled as a “spring-mass model” comprised of a massless linear leg spring attached to a point mass representing the center of mass (COM) of the entire body (Blickhan,1989). In the model, vertical stiffness (K_{vert}; the ratio of the vertical leg spring compression and the peak vertical ground reaction force at the middle of the stance phase) is known to strongly influence running performance (Arampatzis, Brüggemann & Metzler, 1999). Although K_{vert} during running in transtibial amputees is documented (Hobara, Baum, Kwon, Miller, Ogata, Kim & Shim, 2013), little is known about the K_{vert} in transfemoral amputees. The aim of this study was to investigate K_{vert} during sprinting in a transfemoral amputee.

METHODS: One elite sprinter with a unilateral transfemoral amputation was instructed to perform maximal sprinting (on average at 8.56 m/s) in the middle of a 110-m indoor track. Vertical ground reaction force data (vGRF) was collected using four force plates sampled at 1000 Hz. The vGRF data was filtered using a second order, low pass Butterworth filter with a cut-off frequency of 150 Hz. K_{vert} was determined from the regression slope of the profile when the vGRF was plotted versus the COM displacement during the early stance phase. Vertical COM displacement was calculated from double integration of the COM acceleration with respect to time. Assuming that the lower extremities behave according to a simple spring-mass model, the correlation between vGRF and COM displacement during the ground contact phase should be greater than r = 0.80 (Granata, Padua & Wilson, 2002). Thus, we determined whether the correlation coefficient between the latter two variables was >0.80 for the subject. We also compared the K_{vert} of the intact (INT) and prosthetic limbs (PST).

RESULTS: Figure 1-A shows a typical example of the relationship between vGRF and vertical COM displacement during the stance phase. Both legs were compressed from the touchdown, and the vGRF increased with COM displacement. In INT, the vGRF value peaked at the moment of maximum leg compression (middle of the stance phase) and subsequently decreased with extension of the leg until take-off. On the other hand, the curve in PST depicts quite different behaviour in the first and second half of the stance phase. The correlation between the vGRF and COM displacement was 0.877 in INT and 0.618, respectively. K_{vert} was relatively lower for INT than PST (Figure 1-B).

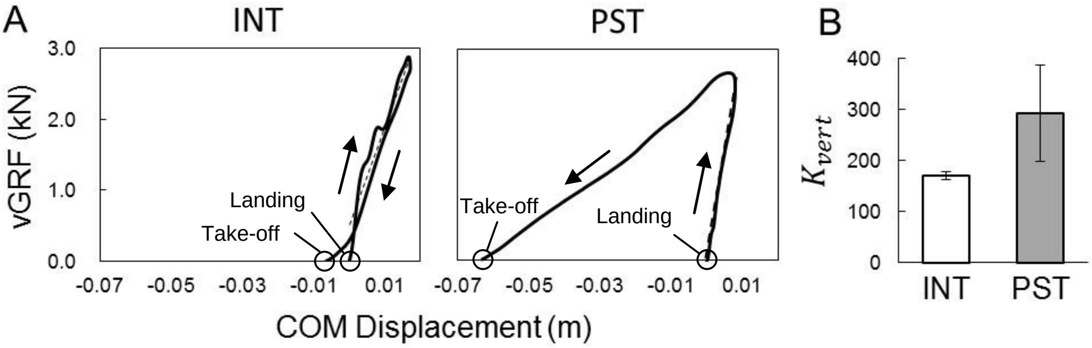

Figure 1: A: vGRF-COM displacement curves during ground contact for the intact (INT) and prosthetic limb (PST), respectively. The slopes (dotted lines) of these curves represent leg stiffness. B: Comparison of K_{vert} between INT and PST. The K_{vert} was normalized by the subject's body mass and leg length.

DISCUSSION: In the present study, the correlation between the vGRF and COM displacement in INT was > 0.80, but not in PST (Figure 1-A). These results suggest that PST in our transfemoral amputee does not behave like a spring during maximal sprinting. One possible explanation for this result might be due to the characteristics of the prosthetic knee joint. The prosthetic knee joint has a hydraulic resistance controller to prevent unexpected knee flexion during the stance phase. Therefore, the vGRF and COM displacement curves in the first half of the stance phase may be different from those of the second half only in PST. We also found that K_{vert} of PST was greater than INT (Figure 1-B), indicating that the subject in this study has different stiffness regulations for each leg. According to a previous study, the prosthetic knee joint is fully extended at the moment of touchdown during running in transfemoral amputees (Buckley, 1999). If the leg is more extended at the instant of touchdown, the GRF vector will be more closely aligned with each joint, simultaneously decreasing the joint moments and increasing stiffness (Moritz & Farley, 2004). As a result, a hydraulic resistance controller may allow unilateral transfemoral amputees to produce different stiffness regulations between legs.

CONCLUSION: The results of the present study suggest that 1) PST in our transfemoral amputee does not behave like a spring, and 2) K_{vert} in PST is greater than INT for a transfemoral amputee due to different stiffness regulations between legs.

REFERENCES:

Arampatzis, A., Brüggemann, G.P. & Metzler, V. (1999). The effect of speed on leg stiffness and joint kinetics in human running. *Journal of Biomechanics*, 32, 1349-1353.

Blickhan, R. (1989). The spring-mass model for running and hopping. *Journal of Biomechanics*, 22, 1217-1227.

Buckley, J.B. (1999). Sprint Kinematics of athletes with Lower-Limb Amputations. *Archives of Physical Medicine and Rehabilitation*, 80,501-508.

Moritz, C.T. & Farley, C.T. (2004). Passive dynamics change leg mechanics for an unexpected surface during hopping. *Journal of Applied Physiology*, 97, 1313-1322.

Granata, K.P., Padua, D.A. & Wilson, S.E. (2002). Gender differences in active musculoskeletal stiffness. Part Ⅱ. Quantification of leg stiffness during functional hopping tasks. *Journal of Electromyography and Kinesiology*, 12, 127-135.

Hobara, H., Baum, B.S., Kwon, H.J., Miller, R.H., Ogata, T., Kim, Y.H., Shim, J.K. (2013). Amputee Locomotion: Spring-like leg behavior and stiffness regulation using running-specific prostheses. *Journal of Biomechanics*, 46, 2483-2489.