EVOLUTION OF METABOLIC AND MECHANICAL COST OF WALKING WITH AN ABOVE KNEE PROSTHESIS SIMULATOR

Aurore Bonnet-Lebrun (1), Xavier Bonnet (1), Amandine Boos (1), Lucas Sedran (1), Cécile Heidsieck (1), Marie Thomas-Pohl (2), Hélène Pillet (1)

1. Institut de Biomecanique Humaine Georges Charpak, Arts et Metiers Sciences et Technologies, France

2. Service de Medecine et de Readaptation, Hôpital d'Instruction des Armees, France

Introduction

At equivalent speed, a clear increase in metabolic cost is observed in lower limb amputees, particularly in above-knee amputees, compared to asymptomatic subjects during walking [1]. Previous articles have suggested that this extra cost may be associated with a lack of propulsion on the prosthetic side, and thus with the mechanical work that must be provided by the amputee to compensate [2]. The aim of this study was to verify this hypothesis by investigating the relationship between metabolic consumption and mechanical work in subjects equipped with a femoral prosthesis associated with feet with and without energy restitution.

Methods

Six asymptomatic subjects (4M/2F) walked in three conditions (Figure 1): 1. without a prosthesis (NA), 2. equipped with a knee prosthesis simulator associated with a foot with energy restitution (ERF) 3. equipped with the same simulator associated with a rigid foot (RF). Kinematic, kinetic and VO2 data were recorded.
To obtain the metabolic cost of walking exclusively, oxygen consumption at rest while standing was subtracted from oxygen consumption measured during walking. The values were normalized to body mass.
The mechanical power of each individual limb (ILM) was then calculated as the dot product of the body center of mass velocity and the resulting ground reaction forces on the lower limb under consideration [3]. Positive and negative work was calculated by numerically integrating the powers over time and normalizing them to body weight. To consider only the work done by the residual joints of the subject, and not that done by the prosthesis, the ILM work was replaced by the work of the hip on the prosthetic side. The total work was the sum of the absolute values of the positive and negative work.

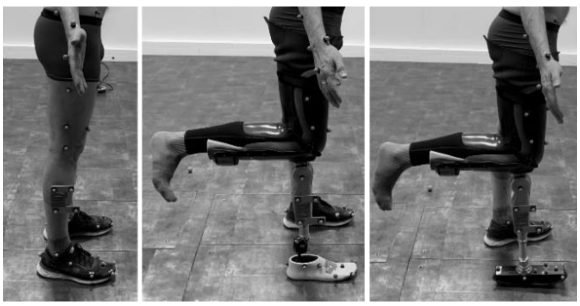

Figure 1: Illustration of the three conditions tested. From left to right: without prosthesis; with the prosthesis simulator equipped with an energy restitution foot; with the same simulator equipped with a rigid foot.

Results

Metabolic rate was doubled between the condition without prosthesis and the two conditions with prosthesis (NA = 10.7 (1.0) $mlO_2.min^{-1}.kg^{-1}$, ERF = 20.5 (2.0) $mlO_2.min^{-1}.kg^{-1}$, RF = 20.5 (2.6) $mlO_2.min^{-1}.kg^{-1}$). The ILM power for the three conditions and the hip powers for the two conditions with prosthesis are shown in Figure 2.
The total mechanical work was equivalent in the three conditions (NA = 1.05 (0.21) $W.kg^{-1}$, ERF = 1.18 (0.28) $W.kg^{-1}$, RF = 1.03 (0.21) $W.kg^{-1}$) but the distribution was strongly asymmetrical for the condition with prosthesis simulator: the mechanical work on the contralateral side was 2.5 times greater than on the prosthetic side. This asymmetry was further exacerbated for the positive work (5.5-fold increase). The negative work was equivalent for the leg on the prosthetic side with both foot types and the condition without prosthesis (NA = -0.26 (0.05) $W.kg^{-1}$, ERF = -0.26 (0.07) $W.kg^{-1}$, RF = -0.21 (0.08) $W.kg^{-1}$). On the other hand, it was increased on the sound side for both types of foot (ERF = -0.34 (0.09) $W.kg^{-1}$, RF = -0.31 (0.07) $W.kg^{-1}$).

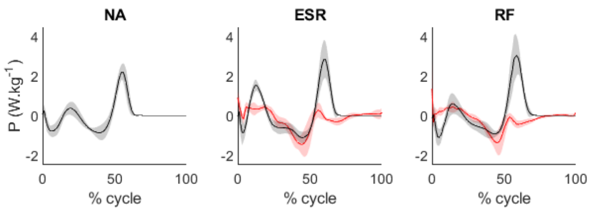

Figure 2: Power curves. Black: ILM power of the sound side; red: hip power of the prosthesis side.

Discussion

Whether or not the foot returns energy has no real impact on the total mechanical work performed by the amputee or on his/her metabolic rate.
The metabolic over-cost measured can probably be explained by the asymmetry in the distribution of mechanical work between the prosthetic and contralateral limbs observed as well as the overall increase in negative work that forces the muscles to function outside their optimal zone of use. This hypothesis could be verified experimentally via EMG or via the use of a musculoskeletal model.

References

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2. Caputao & Collins, Sci. Rep., 4:37-41, 2014.
3. Donelan et al, Proc. R. Soc. Lond. B, 268:1985-1992, 2001.