Optimizing Prosthetic Gait

Wezenberg, D.

2013

Summary

Introduction

Undergoing a lower limb amputation is a life-changing surgery. Unfortunately, a substantial number of people undergo amputation of part of the lower limb. Due to the aging population and a rising number of people diagnosed with diabetic mellitus or peripheral vascular disease this number is expected to grow in the coming years. The ability to walk greatly influences subject's functional independence and quality of life. Not surprisingly, regaining walking ability is one of the primary goals during prosthetic rehabilitation. Within the group of lower limb amputees it is the older person amputated due to vascular deficiency that often experiences the largest difficulties regaining and maintaining walking. In this thesis some of the underlying mechanisms causing these difficulties are investigated using a biophysical approach in which walking is regarded to require an adequate balance between aerobic capacity and aerobic load. The aim of this thesis was to gain insight into the aerobic capacity that subjects possess and relate this to the aerobic load imposed when walking. Additionally, insight is obtained about some of the underlying factors causing the increased aerobic load when walking with a prosthesis.

In Chapter 2 a method to measure peak aerobic capacity in people with a lower limb amputation is described. The peak aerobic capacity is defined as the highest peak oxygen consumption obtained during maximal exercise. In order to measure peak aerobic capacity in a safe and valid manner in people after lower limb amputation requires special consideration of the exercise mode and protocol used. In this Chapter the feasibility and validity of a discontinuous, graded, one-legged, peak exercise test was determined. In total 36 older amputees and 21 healthy controls performed the one-legged exercise test. The healthy controls performed an additional two-legged exercise test. All participants were able to complete the test and blood pressure and electrocardiogram tracings could be adequately monitored to allow for a safe assessment. The exercise test proved to stress the cardio-vascular system to a sufficient extent in both the amputee and control group. With regard to validity it was determined that the one-legged exercise test had both a high construct and a high concurrent validity. To sum, the results of the research presented in Chapter 2 show that the one-legged exercise test provides a feasible and valid assessment of the peak aerobic capacity in older people with a lower limb amputation.

The one-legged exercise test was used in Chapter 3 to determine the magnitude of the peak aerobic capacity and how this was related to the presence, level and cause of the amputation in people with a lower limb amputation. People with an amputation had a 13.1% lower peak aerobic capacity. Differentiation between etiologies revealed that traumatic amputees did not differ to controls, whereas the vascular amputees had a 29.1% lower peak aerobic capacity. Interestingly, no association between peak aerobic capacity and the level of amputation was found. The results corroborated the limited existing evidence and the intuitive notion that the peak aerobic capacity is reduced in people with a vascular amputation.

The lower peak aerobic capacity combined with the increased aerobic load while walking with a prosthesis can result in a high relative aerobic load. In Chapter 4 the relative aerobic load was investigated and the associated effects of level and cause of amputation were determined in the same group of subjects as investigated in Chapter 3. Based on the results, it was concluded that when walking at their preferred walking speed, older vascular amputees walked at a 44.6% higher relative aerobic load than healthy controls. Traumatic amputees compensated for the increased aerobic load by reducing their preferred walking speed to such an extent that the relative aerobic load equaled that of able-bodied controls. They did this even though this entailed walking at a lower walking economy. A data-based model was constructed to determine the potential effect of an increased aerobic capacity on subjects' walking ability in terms of relative aerobic load, walking speed and walking economy. This model denotes that, for example, in vascular amputees a relatively modest increase in peak aerobic capacity of 10% can result in 9.1% reduction in relative aerobic load, a 17.3% improvement in walking speed and a 6.8% improvement in walking economy. These results denote that aerobic training must indeed be considered an essential component of prosthetic rehabilitation.

Whereas in Chapters 2, 3 and 4 the focus was on determining the peak aerobic capacity and the associated relative aerobic load, in Chapters 5 and 6 information is obtained about potential factors causing the increased aerobic load while walking with a prosthesis. In Chapter 5 the mechanical energy cost while walking was investigated using a dynamic walking model. A total of 15 subjects walked both with an energy storage and return (ESAR) prosthetic foot and a solid ankle cushioned heel (SACH) prosthetic foot. Both prosthetic feet were compared with regard to the required step-to-step transition cost while walking. The ESAR foot required the least mechanical work during the step-to-step transition. This was explained by an increased push-off power and a larger forward progression of the center of pressure during single stance in the ESAR foot. Interestingly, previous studies comparing these two prosthetic feet found no convincing evidence that the ESAR feet also required less metabolic cost while walking. To sum, though the ESAR foot is able to reduce the step-to-step transition cost other factors outside those related to step-to-step transition cost influence the overall metabolic energy cost while walking with a prosthesis.

One of the possible factors influencing the overall metabolic energy cost while walking might be an altered balance control. Differentiating between the mechanical energy required for the walking movement and that associated with balance control is a challenge. In Chapter 6 we tried to do this by having nine able-bodied healthy controls walk at an instrumented treadmill while following an projected step pattern composed of either their averaged step pattern (periodic trial), or a step pattern that was an exact copy, including variability of their unconstrained walking trial (variable trial). The novelty of this approach is that we were able to investigate whether balance control strategies can contribute significantly to the overall metabolic energy cost, independent from alteration in the global gait characteristics. Results showed that walking an enforced gait pattern resulted in a metabolic oxygen increase of 8% in the periodic and 13% in the variable trial. It was postulated that the increased metabolic energy cost is related to increased preparatory muscle activation and a more active ankle strategy to control for lateral balance. This Chapter shows that metabolic energy cost can be associated with alterations in balance control strategies that do not alter global gait characteristics.

Conclusion

The overarching aim of this thesis was to enhance our understanding of some of the factors that influence the ability to regain and maintain walking after unilateral lower limb amputation. Based on the results presented in this thesis we can deduce that the peak aerobic capacity plays an important role in subjects' walking ability. This peak aerobic capacity is reduced in vascular amputees, which makes walking a strenuous activity for these patients. The work presented in this thesis shows that relatively small improvements in peak aerobic capacity could potentially lead to significant and clinically relevant improvements in subject's walking ability. Furthermore, this thesis showed that the development of prosthetic feet with adequate and correctly timed push-off power together with an optimal roll-over shape can decrease the step-to-step transition cost. However, the energy required for balance control seems an important factor contributing to the overall metabolic energy cost while walking.

Implication for rehabilitation

In this thesis we postulate that future research ought to involve longitudinal studies with a heterogeneous group of amputees in order to investigate the efficacy of different training protocols and to determine what effect an increased peak aerobic capacity has on subject's walking ability. Additionally, simple dynamic models can be used to gain helpful insight into the mechanical work on the center of mass while walking on different state-of-the-art prosthesis. Though insightful, future studies must be designed that face the challenge of disentangling the metabolic energy cost associated with the mechanical work needed to perform the walking movement and that associated with preserving balance. Information about these underlying causes for the increased metabolic energy cost while walking with a prosthesis will help and aid the development of more efficient and functional prostheses. Moreover, health care professionals must realize that both aerobic and balance training can substantially improve subjects' walking ability, and therefore, ought to be an integrated part of prosthetic rehabilitation.