TRUNK BIOMECHANICS OF TRANSTIBIAL AMPUTEES IN LEVEL AND SLOPED GAIT USING RIGID, HYDRAULIC AND MICROPROCESSOR CONTROLLED ANKLES

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Compensational gait mechanisms, as an increased mediolateral trunk lean, are associated with the development of lower back pain, which is common among individuals with transtibial amputation (TTA). Therefore, the aim of this study was to investigate if different prosthetic ankle devices influence mediolateral trunk angles during gait in TTA. Six TTA and six controls walked in the level and on a positive and negative 5° inclined instrumented ramp using a rigid (RIG), a hydraulic (HYD) and a microprocessor (MPC) ankle component (Chas A Blatchford and Sons, Basingstoke, UK). Prosthetic design did not significantly affect the mediolateral trunk lean in any of the three slope conditions. Therefore, the different prosthetic ankle devices seem to play a minor role for mediolateral trunk lean adaptations. Their potential to reduce lower back pain needs further investigation.

KEYWORDS: amputee gait, transtibial, sloped gait, prosthetic ankle, trunk biomechanics

INTRODUCTION: The loss of the ankle function in below knee amputees leads to reduced power generation and absorption capacities of the residual limb side. As a result, amputees develop gait alterations influencing their level and sloped walking. For example, TTA amputees walk with a reduced residual side knee flexion during stance (Baumgartner, 2016), increased hip extension power outputs to compensate for the lost ankle push-off (Sadeghi, Allard, & Duhaime, 2001; Su, Gard, Lipschutz, & Kuiken, 2007), or reduced pelvis obliquity (Michaud, Gard, & Childress, 2000; Molina-Rueda et al., 2014). Naturally, these compensational movements of the lower extremity are directly connected to changes of the trunk kinematics. Commonly observed is a trunk lean towards the prosthetic side direction, which is associated to be an influencing factor of the significantly increased occurrence of lower back pain among TTA (Ephraim, Wegener, MacKenzie, Dillingham, & Pezzin, 2005; Hendershot & Wolf, 2014). In order to assist the TTA, varying ankle components exist with different technical features. The simplest construction being a rigid ankle device (RIG), allowing no movement in the ankle, while a hydraulic ankle device (HYD) allows a certain amount of dorsi- and plantarflexion with a given resistance. Microprocessor ankle devices (MPC) similarly allow a certain amount of dorsi- and plantarflexion plus additionally adjust the movement resistance to the given movement situation such as level, uphill or downhill walking. While these ankle components have been proved to assist in the level and sloped gait on the basis of temporospatial and lower limb kinematics, little is known on the effect of the trunk movement. It is assumed that the hydraulic and the microprocessor-controlled ankle systems, which allow the amputee to walk faster by providing smoother transition over the prosthetic limb, will affect the trunk kinematics and affect mechanisms leading to lower back pain (Askew, McFarlane, Minetti, & Buckley, 2019; Bai, Ewins, Crocombe, & Xu, 2017; De Asha, Munjal, Kulkarni, & Buckley, 2014). Therefore, the aim of this study was to investigate trunk kinematics of TTA during level, uphill land downhill walking using a rigid, a hydraulic and a microprocessor-controlled ankle device.

METHODS: Six unilateral transtibial amputees (TTA, 1 f, 5 m, 48.0±11.3 yrs, 79.5±10.6 kg, 4 left, 2 right side amputated) and six healthy abled bodied controls (NORM; 3f, 3m, 32.7±6.7 yrs, 69.0±12.7 kg) participated in this study. All of the amputees were classified as K3-Level or higher.

All participants completed six valid gait trials on a hydraulically adjustable ramp system with a walkway of 1.4m x. 6m in downhill (-5°), level (0°) and uphill (+5°) inclination. The TTA participants always started with the RIG ankle condition followed by HYD and MPC ankle condition in randomized order. All ankle system are custom devices and were provided by Blatchford, Basingstoke, UK: RIG – “Esprit”, HYD: - “Elan” with MPC settings: OFF, MPC – “Elan” with MPC settings: ON. All participants were Echelon user in their daily life. The fitting of each prosthesis was maintained by an orthopaedic technician professional. Between each condition, a adaptation period of 15 minutes was completed. Reflective markers were placed according to the Cleveland Clinical marker-set with the markers on the prosthetic side according to McGrath et al. 2018 (McGrath, Laszczak, Zahedi, & Moser, 2018) . Kinematic data of the gait cycle initiated with the prosthetic limb in the middle of the walkway was collected using a 13-camera motion capture system (Oqus, Qualisys, Gothenburg, Sweden) with 200 Hz. Trajectories were filtered with butterworth lowpass filter of 15 Hz. 3D joint angle of the trunk with respect to the pelvis were calculated using V3D (C-Motion Inc, Germantown, Maryland, USA). Differences in the trunk angles between the three different prosthetic ankle conditions and the NORM were calculated over the gait cycle using an SPM oneway ANOVA (α=0.05). To additionally quantify the effect of the differences between the HYD and MPC in comparison to the RIG prosthetic condition Cohen’s d effect sizes were calculated for the peak trunk angle excursions (peak lateral lean towards the prosthetic and sound limb) and its range of motion (RoM).

RESULTS: The time series and the RoM data of the mediolateral trunk angle show an increase from downward gait to level to uphill gait for all participants (Figure 1. Table 1). Between the different ankle conditions, no significant differences exist within each slope inclination. This is supported by trivial and small effect sizes of the RoM (Table 1)

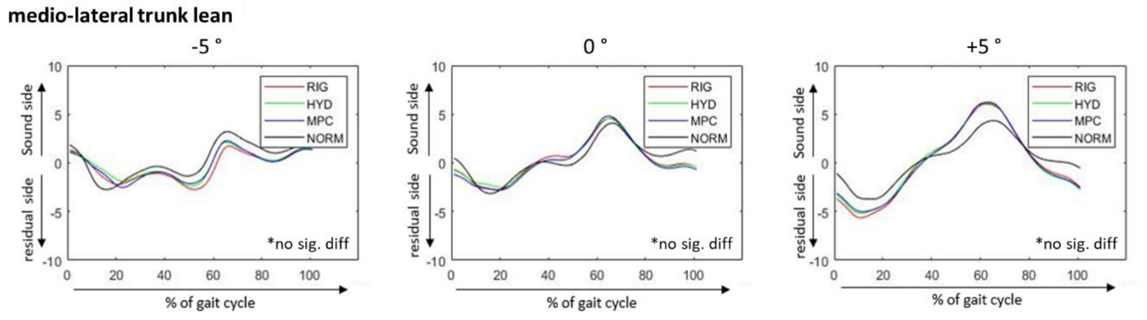

Figure 1: Trunk to pelvis angle in frontal plane for downhill (-5°), level (0°) and uphill gait (+5°)

Table 1: Mean (SD) Range of Motion and peak mediolateral lean for downhill, level and uphill gait with 3 different prosthetic ankle devices (RIG, HYD, MPC) and NORM.

		HYD	RIG	MPC	NORM
0°	Min [°]	-2.74 (1.89)	-2.96 (1.34)	-3.06 (2.13)	-3.22 (0.82)
	Max [°]	4.67 (2.58)	4.74 (2.04)	4.93 (2.29)	4.15 (1.70)
	RoM [°]	7.41(3.05)	7.70 (2.48)	7.99 (2.76)	7.36 (1.15)
	RoM Effect size to RIG	0.10^{+}	0.17*	0.11^{+}	
-5°	Min [°]	-2.84 (1.41)	-3.41 (1.40)	-3.10 (1.23)	-2.79 (0.96)
	Max [°]	2.82 (1.54)	2.42 (1.61)	4.93 (1.84)	4.15(1.99)
	RoM [°]	5.66 (1.56)	5.83 (1.86)	5.98 (1.84)	6.15 (1.45)

	RoM Effect size to RIG	0.10^+	0.19*	0.08^+	
+5°	Min [°]	-5.22 (2.64)	-5.70 (2.19)	-5.07 (2.45)	-3.91 (1.17)
	Max [°]	6.24 (2.42)	6.14 (2.63)	6.44 (2.64)	4.49 (2.65)
	RoM [°]	11.46 (3.40)	11.83 (3.59)	11.51 (3.34)	8.40 (2.29)
	RoM Effect size to RIG	0.11^+	1.14*	0.09^+	

Note: $^+$compared to RIG, *compared to NORM; Range of Motion

DISCUSSION: The main focus of this study was to determine the different influences of three prosthetic ankle devices on the user's mediolateral trunk movement. Earlier studies have shown that the involvement of a hydraulic ankle attached to a regular carbon fibre foot improves the range of motion in plantarflexion and dorsiflexion of the ankle and mimics the natural ankle resistance moment. Resulting from this movability, multiple gait changes and benefits occur (Bai et al., 2017; De Asha, Johnson, Munjal, Kulkarni, & Buckley, 2013; De Asha et al., 2014). For example, Askew et al. (2019) found a significantly reduced mediolateral displacement of the body center of mass, which they explained by a "smoother, less flattering" transition of the body weight from the sound to the prosthetic side. This change allows us to assume, that the known trunk lean of TTA toward the prosthetic side might be reduced with a hydraulic and microprocessor-controlled ankle device. When focussing on sloped walking, transtibial and healthy individuals show similar adaptations to different slope inclinations, but the adaptation magnitudes of transtibial amputees are slightly lower and asymmetrical. Statistically, our data shows within each inclination no significant differences between the groups TTA and NORM. However, the large effect size between RIG and NORM in the uphill condition can be explained by a different movement strategy for the TTA group compared to the NORM group. Additionally, the small to trivial effects between HYD/MPC to RIG indicate, that the prosthetic device does not have a major effect in any of the slope conditions (Table 1, Figure 1).

The medio-lateral trunk lean in this study was calculated as angle between the trunk and the pelvis and therefore is a combination of both segment positions. It is important to highlight that this shows one aspect of the gait posture and either indicates that a) there is no effect or b) it might balance combined effects of the prosthetic ankle devices on the pelvis and trunk segment. For example, pelvis obliquity during stance is known as a shock absorbing mechanism. TTA walk with a decreased pelvis obliquity during prosthetic stance. This adaptation is explained by the reduced damping capacities of the residual limp. The lost ability to plantarflex the foot during early stance creates a stance instability, which is followed by a co-contraction of the knee muscles leading to a reduced knee flexion. As a result, an increased shock transfer into the hip occurs and the hip abductors need to increase the work to maintain upright posture (Hendershot & Wolf, 2014; Michaud et al., 2000; Molina-Rueda et al., 2014; Royer & Wasilewski, 2006; Sadeghi et al., 2001; Sanderson, 1997). The HYD and MPC ankle, by mimicking a more natural plantarflexion, might partly compensate for the lost shock absorption capacities. Therefore, it is possible, that the amputees walking with a HYD or MPC ankle, increase their pelvis obliquity as well as they reduce their trunk lean. A mechanism which would eliminate the assumed reduction of the trunk-pelvis ankle. Therefore, the mechanisms behind the trunk posture with different prosthetic designs and its possible effect on lower back pain cannot be answered by this single parameter and more in-depth analysis will be necessary. Additionally the study design addresses short term adaptation processes to a new device, and adaptations to a longer habituation phase cannot be answered.

CONCLUSION: On the macro-level no significant effects of different prosthetic ankle devices occur on the medio-lateral trunk angle in downhill, level and uphill gait. The mediolateral trunk angle during gait might however not fully mirror the effects of different prosthetic devices and their effect on lower back pain and more factors need to be considered and analysed.

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