Gait & Posture 63 (2018) 80–85

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Full length article

Kinetic differences between level walking and ramp descent in individuals with unilateral transfemoral amputation using a prosthetic knee without a stance control mechanism

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ARTICLE INFO

Keywords:
Transfemoral amputation
Gait analysis
Ramp descent
Prosthetic knee

ABSTRACT

Background: Individuals with transfemoral amputation (TFA) have difficulty in descending ramps. Although individuals with TFA who descend ramps are speculated to have greater biomechanical demands, this has not been quantified.
Research question: How do individuals with TFA wearing a prosthetic knee without a stance control mechanism adapt their gait biomechanics to a slightly declined surface?
Methods: We retrospectively analyzed data of level walking and ramp descent (5° decline) from six subjects with TFA who used a prosthesis without a stance control mechanism. Ground reaction force and joint moment, power, and kinematics were derived from three-dimensional motion capture, combined with force measurement. Kinematic and kinetic variables were compared during level walking and ramp descent using the paired tests.
Results: Compared with level walking, ramp descent increased the maximum contralateral vertical ground reaction force by 16% of the body weight, on average (standard deviation: 20%). Ramp descent tended to induce smaller concentric hip power during late swing and greater hip eccentric power on the prosthetic-side during late stance. Greater biomechanical demands during ramp descent were indicated by increased maximum medial ground reaction force on both sides, and eccentric joint power of the contralateral ankle during stance.
Significance: For individuals with TFA using a prosthetic knee without a stance control mechanism, descending a ramp can increase loading on the contralateral limb during the loading response; slower walking may alleviate the effect. Ramp descent can change prosthetic-side hip muscles' control of the swinging prosthetic limb, eccentric work on the contralateral ankle plantarflexors during stance, and mediolateral balance. All of these factors should be taken into consideration when individuals with TFA learn to descend a ramp.

1. Introduction

Descending a ramp is a demanding task for individuals with transfemoral amputation (TFA), because they must control their prosthetic knee without active control from the knee and ankle muscles, while lowering their body's center of mass. Descending a ramp has often been associated with a greater amount of limb loading in these patients than level walking level [1,2], which can increase the risk for secondary musculoskeletal disorders [3]. However, this is assumed based on biomechanical speculation without quantitative data from the literature [1–3]. In a kinematic analysis [4], researchers reported that individuals with TFA wearing a non-microprocessor or microprocessor prosthetic knee had a reduced flexion angle of the prosthetic-side hip during ramp descent (by 5%, with a 2.9° decline), compared with level walking. This resulted in a shorter step length and easier foot placement. Information on kinetic changes caused by a declined surface would also lead to a better understanding of biomechanical demands during daily activities in those with TFA. Although a growing body of evidence on the use of microprocessor knees during ramp descent exists, data on non-microprocessor-controlled prosthetic knees without a stance control mechanism, which can be used as a quantitative reference representing the performance of conventional prosthetic knees without microprocessor control, are scarce [1–3,5–7].

Movement analysis studies have shown the importance of kinematic

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https://doi.org/10.1016/j.gaitpost.2018.04.043
Received 19 January 2018; Received in revised form 22 March 2018; Accepted 26 April 2018

Table 1
Subjects' characteristics.

ID	Age, y/sex	Height, m	Weight, kg	Post-amputation, y	Cause	Knee[a]	Foot
1	19/M	1.69	98	0.9	Trauma	Mauch	FS3000 (Freedom)
2	30/M	1.74	71	0.4	Trauma	3R80+	1C60 (Otto Bock)
3	30/M	1.71	62	6	Tumor	Mauch	Elation (Össur)
4	47/M	1.71	62	32	Trauma	3R80	1C30 (Otto Bock)
5	45/M	1.74	69	4	Trauma	3R80	1C60 (Otto Bock)
6	50/M	1.74	81	23	Trauma	Hybrid knee	J-Foot (Imasen)
7[b]	63/M	1.60	77	42	Trauma	Mauch	LP Vari-Flex (Össur)
Mean	40	1.70	74	15			
SD	15	0.05	13	17			

ID: identification; SD: standard deviation.

[a] All prosthetic knees provide stance knee flexion, but this function was deactivated during data collection.

[b] One subject (ID7) was excluded from the analysis because of slow ramp descent (0.5 m/s).

Table 2
Ground reaction force, joint moment, and joint power values for level walking (Level) and ramp descent (Ramp) (n = 6).

	Prosthetic				Contralateral			
	Level	Ramp	Difference	p-value	Level	Ramp	Difference	p-value
Max. aft ground reaction, %BW	14 (6)	8 (6)	−6 (6)	0.06	20 (3)	25 (8)	5 (8)	0.19
Max. fore ground reaction force, %BW	9 (2)	13 (2)	4 (2)	0.03*	25 (4)	26 (7)	1 (5)	0.69
Max. medial ground reaction force, %BW	9 (1)	11 (3)	2 (2)	**0.01**	10 (2)	13 (2)	3 (1)	< **0.001**
Max. lateral ground reaction force, %BW	1 (1)	1 (1)	0 (1)	0.18	4 (2)	2 (2)	2 (1)	**0.004**
Max. vertical ground reaction force, %BW	110 (10)	114 (16)	4 (10)	0.56	119 (5)	134 (17)	16 (20)	0.11
Max. stance hip extension moment, Nm/kg	0.50 (0.15)	0.55 (0.15)	0.05 (0.07)	0.12	1.23 (0.17)	0.91 (0.29)	−0.32 (0.21)	**0.01**
Max. hip flexion moment, Nm/kg	0.93 (0.20)	0.93 (0.23)	0.00 (0.09)	0.97	0.38 (0.14)	0.59 (0.23)	0.21 (0.21)	0.05
Max. swing hip extension moment, Nm/kg	0.44 (0.13)	0.46 (0.15)	0.01 (0.08)	0.70	0.34 (0.09)	0.36 (0.14)	0.02 (0.06)	0.52
Max. hip abduction moment, Nm/kg	0.52 (0.18)	0.54 (0.21)	0.01 (0.09)	0.74	0.84 (0.10)	0.85 (0.27)	0.02 (0.23)	0.44
Max. early-stance hip concentric power, W/kg	0.74 (0.19)	0.70 (0.23)	−0.04 (0.21)	0.68	1.66 (0.41)	1.20 (0.36)	−0.46 (0.28)	**0.01**
Max. late-stance hip concentric power, W/kg	0.97 (0.21)	1.02 (0.34)	0.05 (0.26)	0.66	0.94 (0.48)	1.31 (0.40)	0.37 (0.20)	0.03*
Max. late-stance hip eccentric power, W/kg	1.10 (0.28)	1.00 (0.29)	−0.10 (0.29)	0.049*	0.38 (0.12)	0.77 (0.70)	0.38 (0.62)	0.19
Max. swing hip eccentric power, W/kg	0.34 (0.10)	0.51 (0.23)	0.17 (0.16)	0.045*	0.11 (0.08)	0.22 (0.30)	0.11 (0.23)	0.69
Max. stance knee extension moment, Nm/kg	0.11 (0.03)	0.10 (0.03)	−0.01 (0.02)	0.20	0.50 (0.22)	0.79 (0.54)	0.29 (0.66)	0.44
Max. stance knee flexion moment, Nm/kg	0.58 (0.12)	0.51 (0.15)	−0.07 (0.08)	0.07	0.71 (0.10)	0.54 (0.10)	−0.17 (0.14)	0.04*
Max. swing knee flexion moment, Nm/kg	0.20 (0.05)	0.20 (0.07)	0.00 (0.04)	0.76	0.31 (0.05)	0.30 (0.06)	0.01 (0.02)	0.37
Max. early-stance knee eccentric power, W/kg	0.06 (0.06)	0.08 (0.06)	0.02 (0.04)	0.19	0.79 (0.58)	2.03 (2.14)	1.25 (2.42)	0.26
Max. terminal swing knee eccentric power, W/kg	0.78 (0.24)	0.79 (0.46)	0.01 (0.31)	0.94	1.51 (0.27)	1.80 (0.43)	0.30 (0.32)	0.08
Max. knee concentric power, W/kg	0.20 (0.05)	0.21 (0.07)	0.01 (0.02)	0.27	1.39 (0.35)	1.14 (0.55)	−0.25 (0.54)	0.30
Max. ankle dorsiflexion moment, Nm/kg	0.38 (0.12)	0.31 (0.09)	0.07 (0.11)	0.19	0.35 (0.10)	0.39 (0.06)	0.04 (0.10)	0.35
Max. ankle plantar flexion moment, Nm/kg	1.19 (0.13)	1.07 (0.13)	−0.12 (0.07)	0.03*	1.62 (0.08)	1.54 (0.12)	−0.08 (0.15)	0.25
Max. ankle eccentric power, W/kg	0.91 (0.25)	0.88 (0.29)	0.03 (0.25)	0.77	1.02 (0.14)	1.79 (0.46)	0.77 (0.37)	0.03*
Max. ankle concentric power, W/kg	0.75 (0.19)	0.67 (0.14)	−0.08 (0.11)	0.13	3.59 (0.48)	3.49 (1.31)	−0.10 (1.14)	0.84

Values are expressed as mean (standard deviation). Student's paired *t*-test was used. *p*-values with statistical significance are indicated in bold, and those < 0.05 but without statistical significance after Holm's correction are indicated with an asterisk. Max.: maximum, Min.: minimum, BW: body weight.

and kinetic adaptation of the knee and ankle joints for walking on a declined surface in healthy subjects [8–13]. During ramp descent with a prosthetic knee that does not provide stance flexion, the prosthetic limb behaves as an inverted pendulum to prevent collapse of the knee. Descending a ramp with an inverted-pendulum-like prosthetic stance would require greater inferior displacement of the body's center of mass from midstance to contact with the contralateral foot, which can cause increased prosthetic-side hip flexion moment to control hip extension during the terminal stance and help initiate swing. This would lead to a greater impact during the successive contralateral contact, if we assume that the step length during ramp descent is similar to that during level walking. Individuals with TFA may adopt a movement strategy to manage excessive loads on the lower limbs, but this has not been well established in studies that are based on quantitative measurement.

In this study, we investigated the kinetic and kinematic differences between level walking and descending a ramp in individuals with TFA wearing a non-microprocessor-controlled prosthetic knee without a stance control mechanism. Our hypothesis, which is based on biomechanical speculation, was that individuals with TFA would descend a ramp with increased internal-stance hip flexion moment on the prosthetic side to walk in an inverted-pendulum-like manner, and vertical ground reaction forces on the contralateral side would increase.

This study is a secondary analysis of the data of when subjects with TFA walked wearing a prosthetic knee without using a stance-control mechanism. This condition reflects the situation where some persons with TFA walk on a level or slightly inclined surface only with the mechanical stability, which can be provided by knee hyperextension moment [1,14,15], and that some prosthetic knees only with a swing control mechanism (e.g., Ottobock 3R95 and Imasen Dolphin) are available to users with TFA.

2. Material and methods

2.1. Ethical considerations

Data collection was approved by the institutional review board of the authors' institution. Written informed consent was obtained from all the subjects before the data were collected.

2.2. Subjects

We retrospectively analyzed motion and force data that were