A Comparison of the C-leg® and the 3R60 Prosthetic Knee Joint

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Introduction: The C-leg® is an advanced microprocessor-regulated prosthetic knee mechanism. Having a prosthetic knee that is monitored and regulated by a computer during the entire walking cycle (stance and swing phase) is thought to enhance function in a wide range of locomotion modes. It has been suggested that the C-leg improves the amputee's ability to walk down ramps and descend stairs, and it provides stumble control (Stinus, 2000; Michael, 1999; Dietl, 1998; Zahedi *et al.*, 1998). In this study, the C-leg is compared with the 3R60 joint, a multi-linkage passive knee joint.

Aims and Objectives: Quantitative gait analysis was used to evaluate the influence of the C-leg and the 3R60 knee joint on the participants' walking performance. The specific objectives were: (1) to determine the participants' normal and fast walking speed range; (2) to estimate walking efficiency using the Total Heart Beat Index (THBI) (Hood *et al.*, 2002); and (3) to examine the influence of mental loading during level walking, while walking over an obstacle course, and while ascending and descending stairs.

Method: *General:* The study had a crossover design. Each participant wore each prosthetic knee joint for a period of four weeks. Test prostheses were fabricated using a duplication of the participant's current prosthetic socket, and each participant was fitted with a Dynamic Plus foot. *Participants:* Persons with unilateral transfemoral amputation, ages between 40 and 60 years, with a body-weight less than 220 lbs, were included in the study if they presented with no serious complications that interfered with their walking ability; had six or more months of experience with a definitive prosthesis; were able to walk unassisted at a comfortable speed without undue fatigue and without health risk; and were able to climb stairs. *Protocol:* Quantitative gait analysis was performed at the VA Chicago Motion Analysis Research Laboratory (VACMARL). Participants were requested to walk at their preferred and fastest speed, with and without mental loading. The mental loading test consisted of a mathematical calculation task where the participant had to count vocally backwards in three-step increments (first visit) and in 7-step increments (second visit). An obstacle course was set up consisting of a foam section (3m long), narrow slaloms around three chairs, a vacuumized bean-bag section (3m long) simulating sand, a rock section (3m long), a short ramp (1.5m long), a 90-degree turn, and a final stair step (height=13cm). Participants completed the obstacle course twice, once without mental loading, and once with mental loading during which they were timed. The stair portion included one-flight with 10 steps (riser=18.5cm); participants were requested to climb up and down the stairs in their usual manner, once without mental loading, and once with mental loading. During all test activities, heart rate was measured in order to be able to determine the THBI. The THBI is calculated by dividing total heartbeats during an exercise period by the total distance traveled and has been used as an indicator of energy efficiency. All of the participants gave written consent approved by the Institutional Review Board of Northwestern University.

Results: To date, data from three participants have been analyzed. The participants' characteristics are shown in Table 1. Table 2 presents their walking speeds on a level walking surface with and without mental loading. Due to the small number of participants analyzed, statistical tests have not been carried out. When comparing the two knee joints, the mental task had a negative impact on all walking speeds in all participants while wearing the 3R60 joint. With the C-leg, two participants increased their fast walking speed under the mental loading condition, one increased also normal

Table 1: Anthropmetric and Social Data of the Participants. TK= Transfemoral; KD=Kneedisarticulation

Participants n=3	Gender	Age (years)	Height (m)	Weight (kg)	Years since Amputation	Amput. Level	Current Foot	Current Knee	Current Socket
A	male	54	1.73	87.5	28	TF	Flex-Walk	SNS	IC-type
B	female	44	1.64	60.0	43	KD	Ceterus	Total Knee	IC-type
C	male	54	1.71	88.7	3	TF	Multiflex	SNS	IC-type

speed. In Table 3 the results of the THBI are summarized. Better energy efficiency was estimated with the C-leg only during normal walking speed without mental loading. In most other conditions, the energy efficiency favored the 3R60 joint.

Table 2: Walking Speeds [a]Average of 9 trials (min 4 trials; max 21 trials) MT= Mental Task

Participants (n=3)	3R60				C-leg			
	Normal Speed (m/s)		Fast Speed (m/s)		Normal Speed (m/s)		Fast Speed (m/s)	
	w/o MT	w MT	w/o MT	w MT	w/o MT	w MT	w/o MT	w MT
A	1.13 [a]	1.12	1.64	1.62	1.04	0.91	1.70	1.82
B	1.10	0.97	1.34	1.16	1.10	0.96	1.30	1.04
C	0.76	0.48	0.88	0.72	0.82	0.89	1.01	1.08
Median	1.10	0.97	1.34	1.16	1.04	0.91	1.30	1.08

Table 3: Total Heart Beat Index (THBI)
[a] Median; MT= Mental Task

THBI	3R60	C-leg
Walking:		
Normal w/o MT	24.85 [a]	15.43
Normal w MT	22.27	24.45
Fast w/o MT	19.72	21.26
Fast w MT	22.07	22.06
Obstacle Course:		
w/o MT	34.66	41.64
w MT	34.57	43.19
Stairs:		
w/o MT	142.26	156.66
w MT	141.80	198.30

Discussion: In comparison with the 3R60 knee joint, the C-leg demonstrated the tendency to facilitate fast walking speed on a level walkway, especially under the mental loading condition. This suggests that once the participants' main focus was not on walking, the C-leg increased their confidence, so that they were able to walk faster, with almost the same energy efficiency as with the 3R60 knee joint. However, in almost all other conditions energy efficiency was worse with the C-leg, especially during the obstacle course and on stairs. The ease of walking seemed not to be present anymore. During the Obstacle Course, especially under the mental loading condition, the C-leg did not demonstrate better energy efficiency compared with the 3R60 knee joint. For the stairs, participant A changed his stair maneuvering style and came down step-over-step; participant B lost this ability with the C-leg whereas with the 3R60 she was able to do so; participant C had no changes. Hence, overall there was no change in stair negotiation that could explain the C-leg's THBI difference. The THBI results stand in contrast with the results of Buckley *et al*. (1997) who observed reductions in the physical energy cost using an "Intelligent Prosthesis" (IP) from Blatchford. But our results regarding the mental loading are in support with the results of Heller *et al*. (2000) who also demonstrated that an IP was not less cognitively demanding than a conventional knee joint.

Conclusion: The results from this study should be interpreted with caution, as they represent data from three participants. Under the given circumstances, the C-leg produced mixed results. It tends to facilitate fast level walking speed, especially under a mental loading task. However, the 3R60 's energy efficiency, as estimated by the THBI, is generally better than the one for the C-leg.

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