Research Article

Evaluation of Above-Knee Amputees while Walking with Nabtesco Knee Joint

Fatemeh Kheiri

Rehabilitation Faculty of Isfahan University of Medical Sciences, Musculoskeletal Research Centre, Isfahan, Iran.

Abstract | Above-knee amputees may miss their abilities to stand and walk. They have to use various prosthesis components to enhance their abilities to stand and walk. Nabtesco-knee joint is one of knee joint components designed for an active above-knee amputees. There was no study on kinematic, kinetic and stability of amputees with this knee joint. This study was aimed to evaluate the performance of amputees walking with this knee joint. Two above-knee amputees using Nabtesco knee joint were recruited. Their kinematic and kinetics parameters were evaluated by use of the motion analysis system and a Kistler force plate. The stability of subjects during standing and their energy consumption while walking were analyzed by the use of a Kistler force plate and a polar heart rate monitoring. The difference between the kinetic and kinematic between sound and prosthetic sides was evaluated by two sample t-test. The physiological cost index of amputees varied between 0.42 and 0.74 beats per minute. there was no significant difference between the range of motion of ankle, knee, hip and pelvic rang of motions between both sides. The plantar flexion moment in prosthesis and sound sides varied from 0.92-0.98 N/BW and 1.19-1.39 N/BW, respectively (p value of difference <0.05). The energy consumption of amputees was high due to reduced walking speed. However walking with Nabtesco knee joint improved the symmetry of walking and kinematic of the joints in prosthesis side compared to the sound side.

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***Correspondence** | Fatemeh Kheiri, Rehabilitation Faculty of Isfahan University of Medical Sciences, Musculoskeletal Research Centre, Isfahan, Iran; **E-mail:** fateme.kheyri67@yahoo.com
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Introduction

Amputations result in not only physical loss of amputated part of the limb but loss of function, sensation, and body image (Bowker et al., 2002). Presently, there are about 1.6 million persons living with limb loss in the United States, of these, 86% have amputation of the lower extremity (Bowker et al., 2002; Dillingham and Mackenzie, 2002). Twenty-six percent of lower extremity amputees or slightly 357,000 individuals have a transfemoral amputation (TFA) which may be due to vascular diseases, trauma, malignancy, and congenital limb loss/deformity (Dillingham and Mackenzie, 2002).

Various kinds of prosthesis have been designed to improve the ability of the subjects to stand and walk with low energy consumption (Bowker et al., 2002; Seymour et al., 2007; Radcliffe, 1977; Boonstra et al., 1995). Knee joint is one of the critical components of prosthesis which enhance amputee to have a safety ambulation (Boonstra et al., 1995; Boonstra et al., 1996; Buckley et al., 1997). Although many of amputees use non-computerized knee joints (mechanical knee joints) due to accebility and durability, various intelligent knee prosthesis have being designed to improve the performance of amputees during walking. The new design of knee joints enable amputee to control the leg during swing and stance phases simultaneously (Buckley et al., 1997; Chin et al., 2007). Decreased effort in walking, gait symmetry, confidence, lower metabolic cost, and decreased risk of fall are some benefits mentioned for using these novel systems (Bellmann et al., 2010; Berry, 2006; Berry et al., 2009; Blumentritt et al., 2009).

One of the intelligent knee component used for above knee amputees is Nabtesco (Chin et al., 2007; Chin et al., 2003). It is a microprocessor controlled knee joint for active patients that allows the subject to walk step over step, up and down stair and slaps. This system consists of three main parts include rotatory hydraulic control to stabilize the joint in stance phase ,pneumatic cylinder for swing phase control and a MRS system to sense the reaction force (Chin et al., 2003; Chin et al., 2007). In the research done by Chin et al. (Year?) the performance of two old transfemoral amputees walking with mechanical joints were compared with that of Nabtesco knee joints (Chin et al., 2007). The physiological cost index (PCI) which is a sensitive parameters to represent the energy consumption during walking of the subject with traditional joint varied between 0.23-0.47 compared to 0.17-0.2 with intelligent prosthetic joint (Chin et al., 2007). In another research it was shown that subjects walking with intelligent knee joint (Nabtesco) consumed 24.2% more energy than control group at 90 m/min (Chin et al., 2003).

Performance of the normal and handicapped subjects can be evaluated by meaning energy consumption during walking, kinetic and kinematics parameters and by evaluating static and dynamic stability (Rose and Gamble, 2006). There were a few studies on evaluation of the energy consumption of the above knee amputees while walking with this knee joint. Moreover, there was no study on gait and stability of the transfemoral amputees using this knee joint. Therefore, the aim of this study was to evaluate the kinematics, kinetics, stability and energy consumption of the amputees while walking with Nabtesco knee joint system.

Material

Two above knee amputees were recruited in this study. The mean values of the age, height and weight of amputees were 42±4year, 1.72±0.03 m, and 65±4.5kg, respectively. The main inclusion criteria for amputees were age above 18, with unilateral amputation, mechanical functional classification level 2 or 3 with a minimum of 2 year post amputation and use of the current prosthesis for at least 6 months. The exclusion criteria were inability to stand and walk and having any other neuromuscular disorders which influence their abilities in this regard. An ethical approval for this research was approved by ethical committee of Isfahan University of Medical Science. Both subjects were asked to sign a consent form before data collection.

The kinematics of hip, knee, ankle and pelvic, the forces applied on the leg, and the moments transferred through joints were the parameters collected by Motion Analysis system. Moreover, stability of the subjects during standing was analysed by measuring the excursion of centre of pressure (CoP) in mediolateral and anteroposterior, path length of the COP sway in mediolateral and anteroposterior planes and by calculating the CoP velocity in the both planes. Energy consumption was analysed using the physiological cost index (PCI) calculated based on heart rate monitoring during walking and resting. The subjects were asked to walk along a level surface to collect five successful trials. The data collected were filtered (Woltring filter with cut off frequency of 10 Hz) and split out to gait cycle interval using heel strike data. For stability analysis, the subjects were asked to stand on the force plate for one minute. They were instructed to look straight ahead to watch a target (a circle with 3 cm diameter), with their head erect and their arms at their sides in a comfortable position. The data collected were filtered with a cut off frequency of 10 Hz. Stability of the subjects was determined using the following equations:

$$COPEAP\ (mm) = X_{max} - X_{min} \ldots\ldots\ldots (1)$$

$$COPEML\ (mm) = Y_{max} - Y_{min} \ldots\ldots\ldots (2)$$

$$PLAM\ (mm) = \sum^{n-1}\sqrt{(x_{i+1} - x_i)^2} \ldots\ldots\ldots (3)$$

$$PLML\ (mm) = \sum^{n-1}\sqrt{(y_{i+1} - y_i)^2} \ldots\ldots\ldots (4)$$

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$$VAP\left(\frac{mm}{min}\right) = \frac{\sum^{n-1}\sqrt{(x_{i+1}-x_i)^2}}{t} \dots\dots\dots (5)$$

$$VML\left(\frac{mm}{min}\right) = \frac{\sum^{n-1}\sqrt{(y_{i+1}-y_i)^2}}{t} \dots\dots\dots (6)$$

Where, COPEAP, COPEML, PLAP, PLML, VAP, VML are the excursion of the centre of pressure in the anteroposterior direction, excursion of the centre of pressure in the mediolateral direction, path length in the anteroposterior direction, path length in the mediolateral direction, velocity of the COP in the anteroposterior direction, and velocity of the COP in the mediolateral direction, respectively. For energy consumption test, the heart rate during walking (10 minutes along an 8 figure tract) and resting (5 minutes before and after walking) were collected using the Polar Electro Finland. The amount of energy consumption during walking, based on the PCI, was determined using the following equation (McGregor, 1979). PCI has been reported to be a valid measure of energy consumption (Rose et al., 1991; Bailey and Ratcliffe, 1995; Rose et al., 1990; Hayes et al., 2005).

$$PCI\left(\frac{beats}{m}\right) = \frac{Hear\ rate\ during\ walking - heart\ rate\ during\ resting\ (beats/min)}{Walking\ speed(m/min)} \dots\dots (7)$$

Table 1: *The spatiotemporal gait parameters and the forces applied on the prosthesis and sound sides of both amputees*

parameters	Stride length (m)	Cadence (steps/min)	Velocity (m/min)	Percentage of stance phase (%)	Fz1 (N)	Fz2 (N)	Fz3 (N)	Fy (N)	Fx (N)
Subject 1									
Sound	1.2 ±0.025	103.6 ±4.92	1.04 ±0.04	63.7 ±2.94	1080 ±15.6	970.3 ±15.6	1100.2 ±10	65 ±11.5	80.2 ±12.2
Amputee	1.28 ±0.055	103.6 ±4.9	1.11 ±0.0798	65.14 ±1.47	1050 ±18.6	960 ±18.2	1090 ±15.2	68.2 ±13	76.2 ±15.2
p-value	0.015	0.5	0.066	0.19	0.045	0.1	0.12	0.25	0.5
Subject 2									
Sound	0.828 ±0.06	59.4 ±4.39	0.407 ±0.041	75.07 ±6.1	1120.9 ±18.14	990.8 ±8.88	924 ±15.5	75.17 ±12.45	83.97 ±11.9
Amputee	0.756 ±0.26	63.6 ±1.34	0.468 ±0.036	59.2 ±0.17	1100 ±18.8	975.7 ±59.83	730.22 ±353	67.31 ±30.66	67.4 ±13
p-value	0.28	0.023	0.011	0	0.028	0.29	0.14	0.3	0

The differences between the gait parameters on sound and prosthetic sides for each subject was evaluated by use of two sample T-test (p-value was set a=0.05).

Results

The walking speed of the first and second amputee subjects was 59.24 and 33.5 m/min, respectively. The PCI of the amputees was between 0.42 and 0.74 beats/min. The spatiotemporal gait parameters of sound and prosthetic sides of both subjects are shown in Table 1. As can be seen from this table the stride length of subject 1, in prosthesis side was more than that in sound side (p-value=0.0). Although there was no difference between speed of walking of sound side and prosthetic side in subject 1, the walking speed decreased significantly in the subject 2.

The mean values of the peak of the forces applied on the sound and prosthesis sides are shown in Table 1. There was only a different between first peak of vertical force applied on the prosthesis and sound sides in both subjects.

The kinematic of hip, knee, ankle and pelvic are shown in Table 2 and 3. As can be seen from this table although in both subjects the range of dorsi/plantar flexion of ankle joint decreased in prosthetic side compared to sound side, the difference was not significant (p-value>0.05).

There was no difference between the range of motion of the knee joint in three planes of sound and prosthetic sides in both subjects. The range of motion of the hip joint in the sagittal plane was 35.35±4.9 degree in sound side and 43.59±4.2 in the prosthetic side in subject 1. However, it was 47.9±3.97 degree in sound side and 44.31±6.43 in prosthetic side in subject 2 (p-value=0.26). The range of motion of the hip joint decreased significantly in both subjects in frontal plane (p-value<0.05). In subject 1 the range of motion of the pelvic in three planes decreased significantly in prosthetic side however in subject 2 the difference was seen only in frontal plane. Figure 1 shows the patterns of ankle, knee, hip and pelvic in amputed and sound sides, respectively.

Table 2: *The range of motions of the ankle and knee joints in prosthesis and sound sides*

Parameters	Ankle X	Ankle Y	Ankle Z	Knee X	Knee Y	Knee Z
Sound1	35 ±4.3	26.4 ±1.26	32.84 ±3.77	61 ±17.2	33.78 ±20	29.6 ±11.7
prosthetic	30.41 ±3.1	19.67 ±1.62	16 ±2	61.66 ±1.42	8.29 ±1.77	19.67 ±10.3
p-value	0.098	0	0	0.47	0.16	0.147
Sound3	29.6 ± 10.6	18.71 ±5.5	12.75 ±0.74	62.8 ±4.4	10 ±2.45	19.23 ±8.81
prosthetic	19.75 ± 1.6	21.7 ±18.7	11.4 ±2.31	74.53 ±19.61	9.53 ±7.35	15 ±3.76
p-value	0.07	0.4	0.22	0.2	0.45	0.21

Table 3: *The range of motions of the hip and pelvic in prosthesis and sound sides*

Parameters	Hip X	Hip Y	Hip Z	Pelvic X	Pelvic Y	Pelvic Z
Sound1	35.35 ±4.9	13.47 ±5.2	12.8 ±1.1	7.23 ±0.13	9.32 ±0.26	7.55 ±1.2
prosthetic	43.59 ±4.2	7.1 ±1.53	14.3 ±4.25	4.9 ±1.68	6.42 ±3	4.9 ±0.53
p-value	0.03	0.08	0.244	0.011	0.048	0.024
Sound3	47.9 ±3.97	15.55 ±0.46	10.5 ±1.14	5.7 ±2.48	13.16 ±1.82	15 ±1.97
prosthetic	44.31 ±6.43	11.07 ±3	15.6 ±2.96	4.07 ±2.57	8.92 ±1.68	15 ±1.59
p-value	0.26	0.06	0.04	0.22	0.013	0.49

The moment applied on the hip, knee and ankle joints are shown in Table 4. The plantar flexion moments of the hip joint in prosthetic side varied between 0.92 and 0.98 NM/Kg, in contrast it was between 1.19 and 1.39 in the sound side (p-value of difference between sound and prosthetic side was less than 0.05). The extensor moment of the hip joint increased slightly in prosthesis side compared to sound side, however the difference was not significant. There was a slight increase in adductor moment of ankle, knee and hip joints in prosthetic side compared to sound side.

Discussion

The performance of amputees during walking is influenced by various prosthetic components in which knee joint plays a significant role (Barr et al., 2012; Dillon and Bach, 2009; Johansson et al., 2005; Jaegers et al., 1995; Bellmann et al., 2009). Various kinds of knee joint have being designed for amputees including mechanical and intelligent knee joints. Nabtesco intelligent knee is a microprocessor controlled knee joint designed especially for active patient to have a safe and stable joint during walking, standing and stairing (Chin et al., 2003b). There were a few studies only on the energy consumption of amputees while walking with this system. Due to lack of information regarding the performance of this knee joint it was aimed to evaluate the abilities of amputees during standing and walking with this system.

As can be seen from the results of this research, the COP excursions of the amputees during standing varied between 44.37±20.24 mm and 71.14±20.4 mm in AP and between 35.15±2.42 and 38.35±2.5 mm in ML planes, which is more than those of normal

Table 4: *The moments applied on the ankle, knee and hip joints in the sound and prosthesis sides*

Parameters	MXE ankle	MY ankle	MZ ankle	MX knee	MY knee	MZ knee	MXF hip	MXE hip	MY hip	MZ hip
Sound1	1.19 ±0.16	0.39 ±0.18	0.11 ±0.015	0.18 ±0.113	0.39 ±0.158	0.0325 ±0.015	0.55 ±0.44	0.58 ±0.17	0.8 ±0.33	0.22 ±0.056
prosthetic	0.98	0.56 ±0.19	0.17 ±0.048	0.083 ±0.06	0.39 ±0.11	0.037 ±0.006	0.416 ±0.1	0.76 ±0.1	0.96 ±0.012	0.067 ±0.015
p-value	0.03	0.06	0.05	0.23	0.43	0.66	0.15	0.07	0.35	0.013
Sound3	1.39 ±0.16	0.29 ±0.158	0.097 ±0.015	0.14 ±0.173	0.29 ±0.158	0.0325 ±0.015	0.5 ±0.34	0.5 ±0.17	0.85 ±0.33	0.2 ±0.076
prosthetic	0.92 0	0.46 ±0.09	0.17 ±0.043	0.063 ±0.66	0.36 ±0.11	0.033 ±0.006	0.316 ±0.1	0.7 ±0.1	0.9 ±0.002	0.063 ±0.005
p-value	0	0.07	0.045	0.23	0.43	0.46	0.18	0.08	0.25	0.016

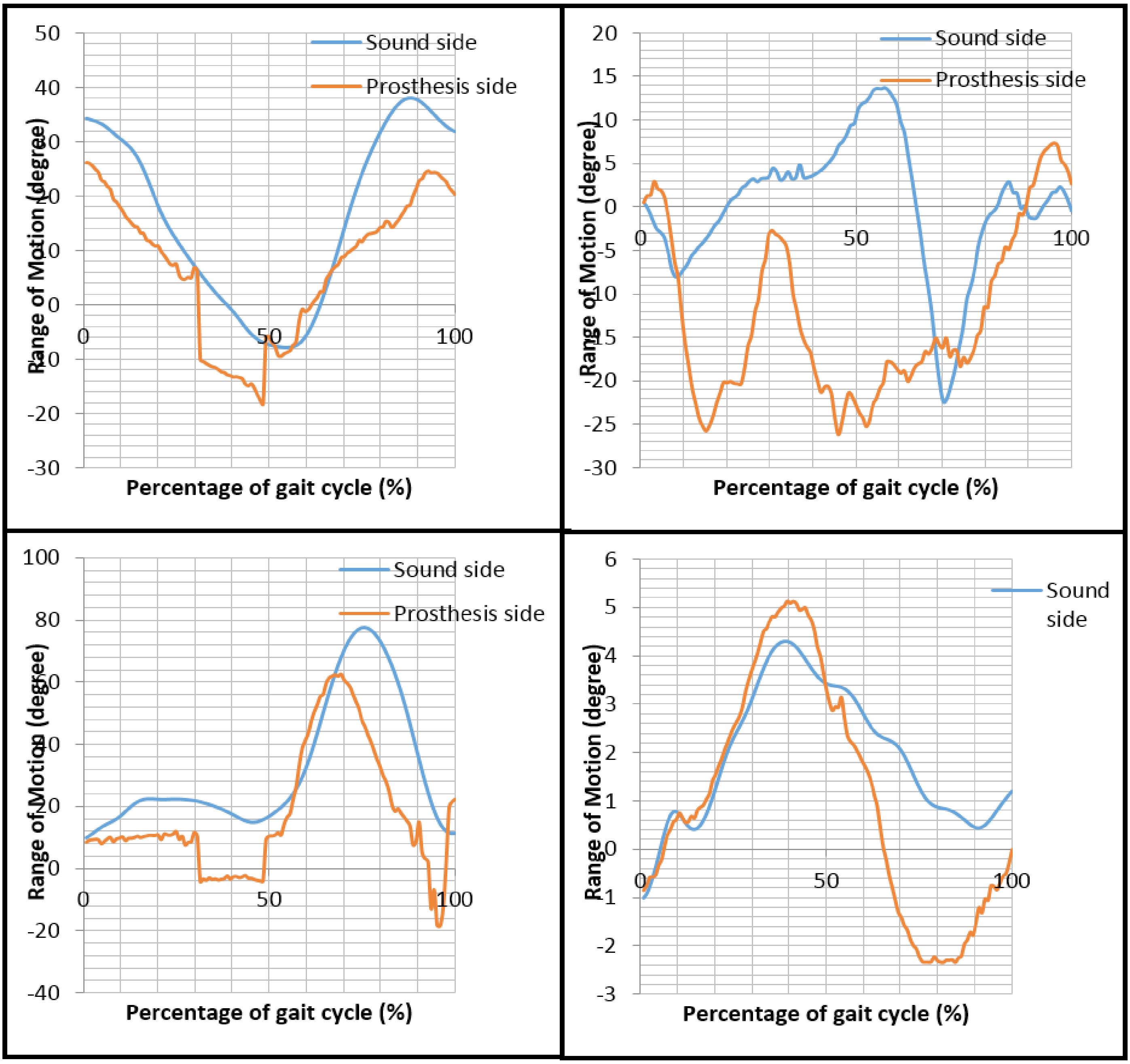

Figure 1: *The patterns of motions of the hip (top, left), ankle (top, right), knee (down, left) and pelvic (down, right) of the sound and prosthesis sides of the first subject*

subjects (Karimi and Esrafilian, 2013; Doyle et al., 2005). The main parameters influencing the performance of amputees during standing is the alignment of prosthesis components and also the strategies which are used by the subjects to restore their balance (Yang et al., 1991). Therefore, it cannot be concluded that these above knee amputees had problems in alignment of prosthesis components.

The result of PCI which is a reliable index to reflect energy consumption confirmed that the PCI of the amputees varied between 0.42 and 0.74 beats/minute. Based on the result of the research done on normal subjects, the PCI of able bodied subjects is nearly 0.2 to 0.3 beats/meter (Rose and Gamble, 2006; Bailey and Ratcliffe, 1995). In the research done by Chin et al On two transfemoral amputees walking with Nabtesco knee joint, the PCI was reported between 0.17 and 0.47 beats/m, which is less than that of the current research (Chin et al., 2007). However, the walking speed of subject in that research was between 21 and 63 m/min, which seems to be less than that of the current research. The result of energy consumption of this research cannot be compared with that done by Chine et al. In that research the age of the subjects was between 76 and 81 years (Chin et al., 2007).

Taheri et al showed that the walking speed of the amputees walked with 3R16and 3R21knee joints varied between 30.4 and 66.7 m/min which was nearly the same as that of this research (Taheri and Karimi, 2012). Regarding the kinematic of knee joints, there was no difference between the range of motion of the knee between prosthesis and sound limbs. It means that this knee joint improved the symmetry of motion of the knee joint (Chin et al., 2003). It provides enough stability during stance phase and mobility (knee flexion) during swing phase. It contrast to the traditional knee joints such as 3R16 and 3R21, the pattern of motion and the range of motion of the knee joint is more symmetrical (Chin et al., 2003). There was some difference between the hip joint range of motions in the both subjects, which seems to be due to restriction provided by socket and alignment of prosthetic component.

The research also focused on the moments transmitted through lower limb joints. For example the flexor moment of hip joint decreased slightly, compared to extension moment which increased slightly. The main reason related to alignment of prosthesis component which was in extended posture.

Conclusion

The result of this study showed that amputees with Nabtesco knee joint had a more asymmetrical gait with less energy consumption during walking.

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