Original article

Evaluation of the gait performance of above-knee amputees while walking with 3R20 and 3R15 knee joints

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Background: The performance of the subjects with above-knee amputation is noticeably poorer than normal subjects. Various types of components have been designed to compensate their performance. Among various prosthetic components, the knee joint has great influence on the function. Two types of knee joints (3R15, 3R20) have been used broadly for above-knee prostheses. However, there is not enough research to highlight the influence of these joints on the gait performance of the subjects. Therefore, an aim of this research was to investigate the performance of the above-knee amputees while walking with 3R15 and 3R20 knee joints. **Materials and Methods:** 7 above-knee amputees were recruited in this research study. They were asked to walk with a comfortable speed to investigate the gait function of the subjects with 3 cameras 3D motion analysis system (Kinematrix system). The difference between the performances of the subjects with these joints was compared by use of paired *t*-test. **Results:** The results of this study showed that, the performances of the subjects with 3R20 were better than that with 3R15. The walking speed of the subjects with 3R20 was 66.7 m/min compared to 30.4 m/min (P-value = 0.045). Moreover; the symmetry of walking with 3R20 was more than that with 3R15, based on the spatio- temporal gait parameters values (P-value <0.05). **Conclusion:** The difference between the performances of the subjects with 3R20 and 3R15 knee joints was related to the walking speed, which improved while walking with 3R20 joint.

Key words: Amputation, artificial limbs, gait, knee prosthesis

INTRODUCTION

The earliest report regarding the prosthetic usage returns to the time of *Rig-Veda* period, which is between 3500-1800 BC.[1,2] The causes of amputation varies in different countries, they are trauma and vascular diseases in the developing and developed countries, respectively. It has been reported that an amputation incidence is between 2.8 and 43, per 100000. The percentage of the below knee (BK) amputation is more than that of the other levels (43%, 29% and 24% for, below knee, above knee and knee disarticulation, respectively).[2-4]

The above knee (AK) amputees use various prostheses in order to stand and walk. They can be fitted with either modular or exoskeletal prostheses, however, the modular designs are well fitted and easier to use than the exoskeletal designs. Moreover, the willingness of the subject to use the modular prostheses is more than that of the conventional ones.[1,3,5-8] Improvement innovations have been made concerning the fitting of the prosthesis socket, socket material and industrially prefabricated prosthetic components.[9] Although the role of the socket, the shank, foot and ankle complex are important and affect the performance of the AK amputees while walking, the function of the knee join is more important.[10-12] Probably, no other component of the artificial limbs has received as much attention from designers, as the knee joint.[7,8,13-15] Several hundred types of knee joints have been produced and offered to public, but relatively few designs have been used widely. It has been fundamentally accepted that the knee joint of a prosthesis must have a dual function, fulfill the control of the leg during standing and stance phase of walking and control the shank during swing phase.[3,7,12]

The range of motion of the knee and ankle joints during walking has been investigated by many researchers during normal walking,[16-18] however, there is not much research regarding the amputees. Influence of various components of the knee and ankle joints on the performance of the subject while walking has been investigated by only a few researchers.[1,5-8,11,13,15,19,20]

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Lee and Hong evaluated an effect of prosthetic ankle mobility on the gait performance of transfemoral amputees, wearing knee joints with a stance phase control.[21] The pattern of walking of the AK amputees with two different knee joints (3R20 and Tehlin knee joints) was studied by Boonstra *et al*.[10] Moreover, Maaref *et al* investigated the difference between the gait performance of the subjects during walking with microprocessor controlled and swing phase control prosthetics knee joints.[22] A comparison of the gait patterns of transfemoral amputees using single axis prosthetic knee (proteor's Hydro cadence system), with that of the other knee joints was carried out by Spain *et al*.[19]

However, there is not enough research regarding the gait performance of the amputee with other commonly used knee joints. Some types of the knee joints, such as 3R15 and 3R20 have been used exclusively by most of the AK amputees. However, to author's knowledge, there is not any research to compare the gait function of the amputees while walking with the aforementioned knee joints. Therefore, it was aimed to compare the functions of the knee joints in a group of above knee amputees.

MATERIALS AND METHODS

A group of 7 traumatic above-knee amputees were recruited in this research study (clinical trial study registered as 1734 in University of Rehabilitation and Welfare Sciences, Tehran). The main criteria for selecting the patients were, having no contraindication for standing and walking with prosthesis, using the current prosthesis for at least 5 hours per day, and had been amputee for 2 years at the time of study. The characteristics of the subjects, participated in this research project are shown in table 1.

The following parameters were evaluated in this research project:

- Stump length (which is the distance between the distal end of the stump and the hip joint)
- Stump muscle strength (which is referred to the strength of the stump muscles). It was measured based on the protocol developed by Kendal, which was scored between 0 and 5 as follows:[23]

Grade 0: Complete paralysis
Grade 1: Flicker of contraction present
Grade 2: Active movement with gravity eliminated
Grade 3: Active movement against gravity
Grade 4: Active movement against gravity and some resistance
Grade 5: Normal power

Moreover, the strength of the flexor and extensor muscles in the stance side and sound side was measured by the use of dynamometer (an accuracy of the dynamometer was ± 1%).[24] Kinematic assessments were performed in the gait lab using 3 cameras, 3D gait analysis system (Kinematrix, MIE Leeds). The data were analyzed by use of a Biomechanical model, developed by Matlab software, based on the recommendation of Winter.[25] This model allowed calculation of joint angles from raw collected data.

Procedure

This clinical trial has been carried out in the gait analysis laboratory of Amin Hospital of Isfahan University of Medical Sciences. An ethical approval agreement was obtained from Isfahan University of Medical Sciences Ethics committee. Moreover, a consent form was signed by each participant before running the test.

The markers used in this research were 14 millimeters spheres, covered with a reflective sheet that could be recognized by the cameras. Markers were used for the right and left greater trochanters (RGT and LGT), the lateral and medial sides of right and left knee joints (RMK, LLK, RLK, LMK), medial and lateral sides of right and left lateral malleoli (RLM, RMM, LLM, LMM), right and left heel (RH, LH), right and left first metatarsal heads (RMT1, LMT1), and right and left fifth metatarsal heads (RMT5, LMT5), as is shown in figure 1.

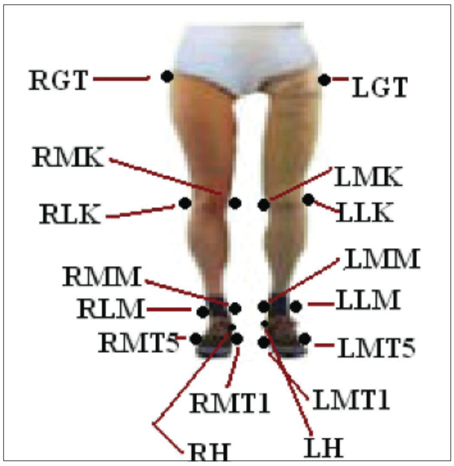

Figure 1: The marker attachment protocol used in this research study

Table I: The criteria of the subjects participated in this research study

Parameters	Number	Side of amputation	Age (year)	Duration of amputation (year)	Mass (kg)	Height (m)	The duration of using the current prosthesis (year)
Mean value	7	Right (3), left (4)	43 ± 9	10 - 14	54 ± 9.1	1.59 ± 0.1	2 - 4

There was no problem in using the markers during walking with the prosthesis as they were attached on the relevant sections of the prosthesis. The marker attachment process began from the most distal segment of the lower extremity.

Weight and height of the subjects were recorded when the subjects attended the gait lab. Then, the subjects were asked to walk with a comfortable speed for one hour with the prosthesis, with a 3R15 knee joint, figure 2. The alignment of the prosthetic components with this type of knee joint was controlled by two expert prosthetic technicians according to the recommendations of the manufacture.[12,13,26] Then the subjects were asked to walk at a comfortable speed along the gait lab. The walking tests were repeated to collect 5 successful trials (the data were recorded with a frequency of 50Hz). In the next session, the same procedure was repeated in walking with the prosthesis with a 3R20 knee joint, figure 2.

The mean and standard deviation of the aforementioned parameters (spatio-temporal gait parameters, strength of stump muscles and stump length) were determined. To determine the correlation between the gait parameters and the strength of the stump musculature, Pearson correlation coefficient was calculated. The difference between the gait performance of the subject while walking with 3R15 and 3R20 knee joints, was determined by the use of Paired t-test. The normal distribution of the parameters was evaluated by the use of Shapiro- Wilk test. The significant level was chosen as 0.05.

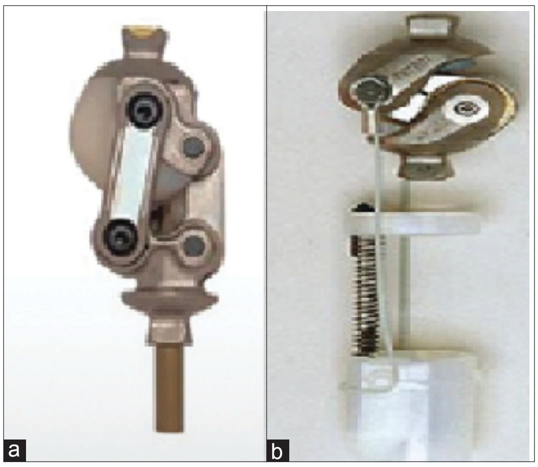

Figure 2: The 3R20 and 3R15 knee joints produced by Otto Bock company (A and B, respectively)

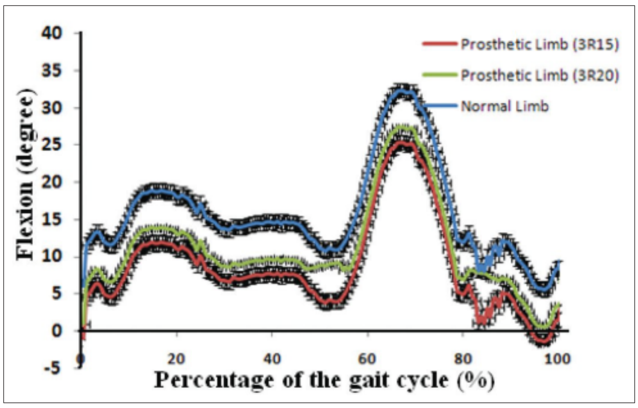

Figure 3: The pattern of the knee joint angle in the sound side, prosthetic side with 3R15 and 3R20 knee joints

RESULTS

The mean values of the stump length, and muscle strength of the amputed and sound sides are shown in table 2. The strength of the hip flexor muscle in the prosthetic side and sound side was 101.07 ± 25.08 and 112.4 ± 28.96 N, respectively. There was no significant difference between the hip extensor muscle force in amputee and sound sides (*P*-value >0.05).

The mean values of the spatio-temporal gait parameters while walking with the both knee joints are presented in table 3. The walking velocity of 3R15 knee joint was significantly less than that of 3R20, 30.04 ± 0.38 and 66.081 ± 3 m/min, respectively, (*P*-value = 0.045). There was no difference between the walking speed of normal and amputation with 3R20 knee joint. The stride length of amputee in walking with 3R15 was 28.8 ± 14.4 compared to 46.35 ± 18.3 m for 3R20 (*P*-value = 0.045). The percentage of stance phase also differed while walking with 3R15 and 3R20 knee joints; it was 65.4 ± 5 for 3R15 and 35.9 ± 7 for 3R20.

The angle of the knee and ankle joints during walking, regarding the amputee and normal sides are shown in figures 3 and 4. The maximum knee flexion angle in walking with 3R15 was 9.3 ± 8.3, compared to 8.35 ± 7.1 degrees in walking with 3R20 (*P*-value =0.23). Table 4 shows the angle of the kinematic parameters during walking with both the knee joints. There was a significant difference between the peak angles of the knee and ankle joints between the normal and amputee sides.

The correlation between the gait performance of the subjects while walking with both 3R15 and 3R20 knee joints, and the

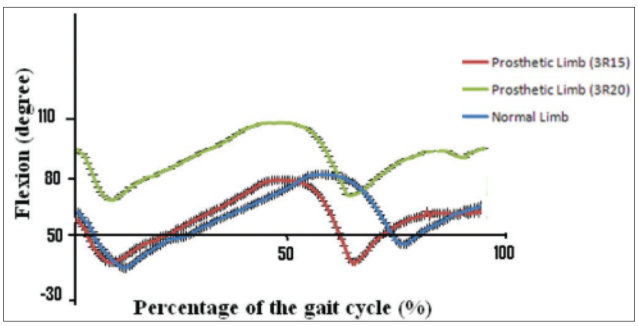

Figure 4: The pattern of the ankle joint angle in the sound side, prosthetic side with 3R15 and 3R20 knee joints

Table 2: The mean values of the stump lengths and muscular strength in both amputed and sound sides

Parameter	Stump length (cm)	Hip flexor (prosthesis side)	Hip flexor (sound side)	Hip extensor (prosthesis side)	Hip extensor (sound side)
Mean value (±SD)	27.36 ± 4.5	101.07 ± 25.08	112.14 ± 28.96	110.7 ± 51.9	123.28 ± 27.2

Table 3: The spatio– temporal gait parameters while walking with two types knee joints

Parameters	Step length (cm)	Cadence (steps/min)	Stance (%)	Walking velocity (m/min)
3R15	28.8 ± 14.4	52.17 ± 13.2	65.4 ± 5	30.04 ± 0.38
3R20	46.35 ± 18.3	71.94 ± 16.43	35.9 ± 7	66.68 ± 3
Normal side	56.51 ± 27.8	59.09 ± 18.53	58.6 ± 1	66.72 ± 1.03

Table 4: The maximum angle of the knee and ankle joints, accelerations of the hip, knee and ankle joints in the sound and amputee sides

parameters	Max knee stance	Max knee swing	Max ankle stance	Max. ankle swing	Max accelerate (knee)	Max accelerate (ankle)	Max acceleration (hip)
3R15	9.3 ± 8.3	22.5 ± 9.9	51.33 ± 35.6	68.98 ± 13.4	10.33 ± 10.9	26.43 ± 13.0	4.7 ± 1.32
3R20	8.35 ± 7.1	23.8 ± 20.6	65.7 ± 20.6	99.4 ± 43	5.5 ± 2.3	25.7 ± 12.9	6.1 ± 1.8
Normal	49.9 ± 22.2	30.9 ± 15	51.57 ± 34.4	80.7 ± 16	7.26 ± 6.49	17.35 ± 12.7	4.7 ± 1.32

strength of the stump muscles were studied by the use of Pearson correlation test. The results of this test show a high significant correlation between theses parameters ($R = 0.83$).

DISCUSSION

Various types of prosthetic components have been designed to improve the performance of the subjects while walking and standing. However, the function of the knee joint is most important and effective in contrast to other components. Probably, no other component of artificial limbs has received as much attention from designers as the knee joint. Various types of the knee joint have been designed to fulfill a dual function of stability during stance phase and mobility during swing phase.[8,13,14,19] Although the designs of the knee joint have been improved significantly in contrast to the traditional designs, the patients experience some problems during walking.[19]

As can be seen from the results of this research study, presented in tables 2-4, there is a huge gap between the performance of the normal subjects and that of the above knee amputees (based on the results of the research, done by Whittle and Murry *et al*.[27,28] The performance of the amputees is significantly lower than that of the normal subjects.

The mean value of cadence, stride length, and velocity during normal walking were 110 ± 6 steps/min, 1.4 m and 87 m/min, respectively[27] compared to 52.17 steps/m, 57.6 and 30.4 in walking with 3R15, and 71.94 steps/min, 92.7 m and 66.68 m/min with 3R20 knee joint, which represent a significant difference between the performance of the normal and amputee subjects. Farahmand *et al*. in their research, which was undertaken on 5 AK amputees with both 3R15 and 3R20 knee joints, showed that the mean value of stride length and walking velocity were 1.003 ± 0.12 and 0.668 ± 0.196 m/min, respectively,[29] which is nearly the same as the results of the current research study.

Although the spatio-temporal gait parameters were not significantly different between the prosthetic and intact limbs in other research studies,[19,29,30] the mean values of these parameters were significantly lower in walking with prosthesis with 3R15 knee joint in contrast to that of the sound side, in the current research study (P-value = 0.045). There was no difference between the function of the intact limb and the prosthetic limb with 3R20 knee joint during walking in this research study (P-value = 0.1). However, there was an asymmetrical walking pattern with prosthetic limb. As can be seen from table 3, the percentage of stance phase in the intact limb was 58.6 compared to 35.6 with 3R20 knee joint. It means that the patients spent more time in the swing phase than in the stance phase.[19] It is believed that this helps to compensate the functional and load bearing limitation caused by an amputation.[12]

There is some difference between the performance of the subjects while walking with 3R15 and 3R20 knee joints. The walking speed of the amputee with 3R15 knee joint was 30.4 m/min compared to 66.68 m/min with 3R20 knee joint. The difference may be related to the bigger step length and the number of cadence, which is more while walking with the polycentric knee joint (3R20) in contrast to that with a single axis knee joint (3R15). Moreover, the subject spent more time in the stance phase while walking with 3R15 compare to 3R20 knee joints.

Although it seems that the mechanism of the 3R15 knee joint provides more stability during the stance phase,[12] the results of this research study showed that the maximum knee flexion angle with both the knee joints was nearly the same. The main point regarding an adjustment of the 3R15 knee joint is that the effective force which produces knee joint flexion, should be more than that of the ground reaction force applied on the limb while walking, if the speed of walking decreases, the vertical ground reaction force decreases simultaneously and the joint would be in an extended position throughout the stance phase.[12] Although the maximum flexion angle of the knee joint during swing phase in walking with 3R15 knee joint was the same as that of an intact limb, it is less than that in normal walking. The peak of flexion angle of the knee joint in 3R20 knee was nearly the same as that in normal walking. Therefore, it can be concluded that the symmetry of walking in 3R20 knee joint is the same as that in normal walking, and is more than that of 3R15.

The strength of the stump muscle (flexor and extensor) has a significant influence on the function of the amputee during walking. As can be seen from the table 2, the strength of the flexor and extensor muscles of the stump was nearly the same, as those in the intact limb. There was a significant correlation between the strength of the muscles and the mean values of the walking speed, cadence and stride length in this research study. This represents an importance of the physical therapist's role to offer appropriate exercises to the patients in order to increase the function of the muscles. Moreover, the magnitude of success of the patients to walk more efficiently with these knee joints depends on the power of their stump muscles. As the power of the muscles surrounding the hip joint was nearly the same in both prosthetic and intact limbs, the angular velocities of the hip and knee joint in both sides was nearly the same.

There are some limitations, which needed to be acknowledged regarding this study, including: Only kinematic parameters were recorded in this study. Additionally, the patterns of upper limb motions did not studied in this research.

CONCLUSION

The results of this research study showed that the performance of the AK amputees while walking with 3R20 may be better than that of 3R15, as the walking speed with the polycentric knee joint was more than that with the single axis knee joint. Moreover, the symmetry of walking with 3R20 is more than that with 3R15. The number of subjects in this research study was limited. Therefore, it is recommended to select a bigger number of subjects in another research study. Moreover, it is recommended to investigate the other parameters, such as the force applied on the limb and the pelvic motion while walking with these knee joints.

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