Fizyoterapi Rehabilitasyon. 2009; 20(3):169-177

Effects of a hydraulic knee joint on energy consumption, gait and patient satisfaction in trans-femoral amputees

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[Ülger Ö, Topuz S, Bayramlar K. Effects of a hydraulic knee joint on energy consumption, gait and patient satisfaction in trans-femoral amputees. Fizyoter Rehabil. 2009;20(3):169-177. *Diz üstü amputelerde hidrolik diz ekleminin enerji tüketimi, yürüyüş ve hasta memnuniyeti üzerine etkisi.*]

Research Article

Purpose: This study was planned to investigate the effects of a hydraulic knee joint on gait, energy consumption and patient satisfaction in trans-femoral amputees. **Material and methods:** Ten patients with a mean age of 22.7±9.4 years who had undergone amputations due to traffic accidents and used prostheses with a mechanic knee joint, polyester quadrilateral socket and dynamic foot initially were included in the study. The patients were fitted with prostheses including a hydraulic knee joint, quadrilateral acrylic socket and a dynamic foot. Gait was assessed using Biodex Gait Trainer 2^{TM} and energy consumption by a 6-minute walk test, quality of life was assessed with the Nottingham Health Profile (NHP), balance was assessed with Berg Balance Scale with each type of prosthesis. A patient satisfaction questionnaire (SATPRO) was also applied. **Results:** The results showed that the prostheses with a hydraulic knee joint and new socket enabled the amputees to walk closer to normal than their previous prostheses did ($p<0.05$). Energy consumption of the patients was lower when the hydraulic knee joint was used compared to the mechanical knee joint ($p<0.05$). According to the NHP, there were no significant differences between the two types of prosthesis except for pain ($p>0.05$). The patients who used hydraulic knee joints stated that they were more comfortable when using prostheses with this type of joint according to SATPRO ($p<0.05$). **Conclusion:** It was shown that energy consumption decreased, subjects' satisfaction increased and gait was near normal by the use of hydraulic knee joint in trans-femoral amputees. It can be concluded that hydraulic knee joint usage can provide convenience to patients clinically.

Key words: Amputees, Gait, Energy metabolism, Personal satisfaction.

Diz üstü amputelerde hidrolik diz ekleminin enerji tüketimi, yürüyüş ve hasta memnuniyeti üzerine etkisi

Amaç: Bu çalışma diz üstü amputelerde hidrolik diz ekleminin enerji tüketimi, yürüyüş ve hasta memnuniyeti üzerine olan etkisini incelemek amacıyla planlandı. **Gereç ve yöntem:** Çalışmaya, amputasyon nedeni trafik kazası olan, yaş ortalamaları 22.70±9.4 yıl olan, daha önce mekanik diz eklemli, polyester quadrilateral soket ve dinamik ayaklı diz üstü protez kullanan toplam 10 olgu alındı. Olgulara hidrolik diz eklemli, akrilik quadrilateral soket ve dinamik ayaklı diz üstü protez yapıldı. Olgular her iki protezleri ile, Biodex Gait Trainer 2^{TM} ile yürüyüş, 6 dakikalık yürüme testi ile enerji tüketimleri, Nottingham Sağlık Profili ile yaşam kalitesi, Berg denge skalası ile denge ve protez memnuniyet anketi (SATPRO) ile hasta memnuniyeti açısından değerlendirildiler. **Sonuçlar:** Elde edilen veriler göre olguların hidrolik diz eklemli protezleriyle normale daha yakın yürüdükleri gözlendi ($p<0.05$). Enerji tüketimleri açısından olgular karşılaştırıldığında hidrolik diz eklemi kullanıldığında enerji tüketimlerinin mekanik diz eklemine göre daha az olduğu saptandı ($p<0.05$). Nottingham Sağlık Profiline göre ağrı dışında diğer alt gruplarda iki eklem arasında fark olmadığı belirlendi ($p>0.05$). Hasta memnuniyeti yönünden olgulara bakıldığında, hidrolik diz eklemi kullanıldığında protezlerini daha rahat hissettikleri tespit edildi ($p<0.05$). **Tartışma:** Bu çalışmada, hidrolik diz eklemi kullanımının enerji tüketimini azalttığı, hasta memnuniyetini artırdığı ve normale yakın bir yürüyüşü paternini geliştirdiği ve bu avantajları açısından klinik kullanım açısından hastalara kolaylık sağlayacağı sonucuna varıldı.

Anahtar kelimeler: Ampute, Yürüyüş, Enerji metabolizması, Memnuniyet.

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Amputation causes significant gait abnormalities. As the amputation level increases functional level decreases, energy consumption increases and abnormal gait characteristics become evident. Trans-femoral amputees suffer loss of the knee and ankle joints and their abilities related to gait.[1-4] Gait abnormalities including impaired climbing up and down stairs, asymmetric gait, reduced gait speed, and increased energy consumption.[4-8] Most of the time even standing may be difficult for these amputees. To be able to stand and walk properly and to gain a higher level of activity with lesser energy consumption, trans-femoral amputees need stronger extremity muscles, wider joint motion and an appropriate prosthesis with which these can be achieved.[9] To solve these problems or to prevent their occurrence, the prosthesis and its components, especially an appropriate knee joint, are of great importance. Gait speed has been increased by the use of pneumatic knee joints and swinging phase symmetry has been improved.[9] Energy consumption will decrease by allowing a gait pattern closer to normal, active standing and maintaining the balance easily. All these improvements will affect the patient's motivation and acceptance of prosthesis and increase satisfaction.[3,4,9] Stump and socket compatibility is another important factor that may contribute to the patient's satisfaction. Ensuring the conformity of the patient's stump in the socket, prevention of any pressure and the development of any sensitivity, are also important.[10]

Reintegration of amputees into the community and enabling their independence in activities of daily living are possible through appropriate selection of prosthetic components, achieving appropriate prosthetic alignment, and successful prosthetic training. The increasing trend of using mobility grading systems also seems to have an important contribution in determining prosthetic components. In our country specific utilization of more functional components is not always possible. Thus, the absence of a guideline presenting flow-charts for proper selection of prosthetic components, few number of evidence based studies conducted by native researchers and insufficient governmental and private insurance systems are of concerns for clinicians while prescribing prosthesis. It is obvious that more scientific researches are needed to enhance social re-integration of amputees into community life and to change the current perspectives of rehabilitation teams. Therefore, the aim of this study was to investigate the effects of the use of hydraulic knee joints on gait, energy consumption and patient satisfaction in trans-femoral amputees.

MATERIALS AND METHODS

Subjects

Ten patients aged 18-25 years who had had unilateral trans-femoral amputations due to traffic accident, and were using prostheses with a mechanic knee joint (Otto Bock, 3R15), quadrilateral socket (polyester lamination), and dynamic foot (Otto Bock, 1D10) were included in the study. Inclusion criteria were as follows: usage of prosthesis functionally for at least two years, having completed prosthetic training upon receiving an initial prosthesis, and being graded as 3 [the patient has the ability or the potential to move with the prosthesis with variable cadence and can simultaneously negotiate most environmental barriers. He/she also has the ability to move about open areas and can undertake occupational, therapeutic and other activities that do not expose the prosthesis to above-average mechanical demands. This also includes those patients who have an increased need for security due to secondary conditions (additional handicaps, special living circumstances) in connection with medium to high mobility activities. In comparison to healthy individuals, the amount of time and the distance that he/she can walk are limited only in non-essential ways)] according to the Otto Bock mobility grading system.[11]

The patients were fitted with trans-femoral prostheses including hydraulic knee joints (Otto Bock, 3R60 EBS Knee Joint), dynamic feet, and quadrilateral sockets (acrylic lamination). In Turkey, mechanic knee joints are routinely prescribed for trans-femoral amputees regardless of their functional level. The logic behind this lies in their suitability for amputees with low to moderate functional levels. They are recommended for patients with up to 100 kg of body weight and with moderate functional demands.[11] Therefore, all the patients in our study were using mechanical knee joints prior to the study.

The hydraulic knee joint, designed for patients with higher mobility levels, was selected as all the subjects included in the study were graded as 3 according to the Otto Bock mobility grading system. Hydraulic knee joints are recommended for patients with a body weight of up to 75 kg/100 kg and moderate functional demands. These joints are also suitable for the higher functional levels. Comfort and safety while walking are the special advantages of this joints.[11]

All patients were told that each approach was being examined for efficacy and each patient signed a written informed consent form. Approval for the study was obtained from the Ethics Committee of Hacettepe University.

Methods

The demographic characteristics including age, weight, height, amputation reason, level, and side, muscle strength and extensibility were recorded. Normal joint range of motion was measured.

The patients were assessed with their own prostheses with a mechanic knee joint, quadrilateral socket, and dynamic foot. Gait assessment was performed on Biodex Gait Trainer 2™ (Biodex Gait Trainer 2™-Biodex Medical Systems, 20 Ramsay Road, Shirley, New York, 11967-4704). They also evaluated with their new modular prostheses with a hydraulic knee joint produced. Patients underwent routine gait training on the Biodex Gait Trainer 2™ and rehabilitation program.[12] The subjects were not informed about the functional or mechanical characteristics of the hydraulic knee joint in order to avoid any effects that may under- or overestimate the outcome and hinder the obtaining of correct data.

While gait analysis was performed on the Biodex Gait Trainer 2™ with the subjects wearing the two prostheses, the weight bearing percentage of the amputated side, the score of the ambulation index, and parameters like the inequalities between amputated and intact sides, the gait cycle, and gait speed were determined.

A six-minute walk test was performed. Energy consumption was calculated by applying a six-minute walking test to subjects using the two prostheses and was expressed as Physiological Cost Index (PCI) (beats/min) [(walking heart rate) -(resting heart rate)/(walking speed (m/min)].[13] The subjects were asked to rest on a chair for at least 10 minutes before the start of the test. Resting heart rate and blood pressure of the subject were measured. Then, patient was instructed to stand up and walk and was reminded not to run or jog. As soon as the patient started to walk the timer was set. With the sound of the timer the subject stopped walking and was allowed to sit on a chair. Heart rate and blood pressure were measured again. The walking distance was recorded.[14] After the 6-minute walking test, walking speed was calculated for the PCI.

Balance was evaluated using the Berg Balance Scale (BBS). The BBS comprises 14 observable tasks common to everyday life measured on a 5-point ordinal scale. The maximum score that can be achieved is 56, with higher scores reflecting better balance. A score of 45 is required for independent safe ambulation.[17]

Quality of life was determined using the Nottingham Health Profile (NHP). The NHP with respect to quality of life and the prosthesis satisfaction survey with respect to satisfaction were applied and their total scores were recorded.[15,16,18] Patient satisfaction was evaluated using the Satisfaction with Prosthesis Scale (Turkish Version), and ambulation activities such as sitting were also evaluated.[12-17] Ambulation activities including ascending and descending stairs and slope, sitting down and getting up from the chair, and walking over an obstacle were recorded with regards to time.[12]

Statistical analysis:

The Wilcoxon paired signed rank test was performed to determine the differences between the hydraulic knee joint and the mechanical knee joint. The data were evaluated using SPSS for

Windows release 11.0. The p value was taken as 0.05 in all statistics.

RESULTS

The mean age of the subjects in the study was 22.7±9.4 years. The demographic characteristics are shown in Table 1.

According to the gait tests, gait speed and gait cycle increased and step inequality decreased with the use of a trans-femoral prosthesis with a hydraulic knee joint comparing to a mechanical one ($p<0.05$). Weight bearing on the amputated side determined using the gait trainer and the ambulation index scores increased when the prosthesis with the hydraulic knee joint was used instead of a mechanical one ($p<0.05$) (Table 2). When the duration of the completion of ambulation activities were assessed, subjects succeeded in the activities, such as sitting-standing, climbing up and down stairs/slope, and walking over the obstacles, in a shorter time if the hydraulic knee joint was used ($p<0.05$) (Table 2).

According to the results of the Berg balance scale, the patients had higher scores, and could stay balanced much longer when they used a prosthesis with the hydraulic knee joint ($p<0.05$) (Table 3).

The PCI, which was obtained from the six-minute walk test, was lower when the subjects used the hydraulic knee joint. In addition, energy consumption was lower than when the mechanical knee joint was used ($p<0.05$) (Table 3).

The satisfaction survey show that the subjects felt much more comfortable while using the prosthesis with the new acrylic quadrilateral socket and the hydraulic knee joint in terms of comfort, cosmetic appearance, and functionality ($p<0.05$) (Table 3).

When the subjects' life qualities were evaluated using the NHP, there were no differences in sub-parameters between the two prostheses except for pain. When the total score was checked, the quality of life score was higher when the hydraulic knee joint was used ($p<0.05$) (Table 4).

Table 1. Demographic characteristics of the amputees.

	X±SD
Age (years)	22.7±9.4
Height (cm)	170.2±7.6
Body weight (kg)	68.7±6.5
Time from the amputation (years)	2.7±0.8

DISCUSSION

There are many publications related to the use of hydraulic knee joints in the literature. Our study is important from the view point of determining gait, ambulation activities, energy consumption and life quality, and their relationship with satisfaction when the prosthetic components are selected as suitable for the mobility grade of the patient.

Our results indicated that subjects with high activity levels using hydraulic knee joints were much more successful in walking, in activities requiring higher degrees of balance and in other functional activities. Moreover, energy consumption of those subjects was decreased compared to when mechanical knee joints were used.

Koehler et al., when they compared hydraulic knee joints with conventional prostheses, found that the gait speed was greater and step lengths were much more symmetrical. Moreover, they emphasized that subjects had lengthier amputated side step lengths with the use of conventional prostheses. However, in the subjects who walked with the hydraulic knee joint, amputated side and the intact side did not have significant or even recognizable differences in the step length.[19]

Table 2. Comparison of gait parameters and ambulation activities of the amputees.

	Mechanic KJ X±SD	Hydraulic KJ X±SD	z	p
Gait parameters				
Velocity (m/s)	0.7±0.2	0.8±0.02	-2.68	0.007*
Gait cycle (s)	0.6±0.02	0.7±0.02	-2.81	0.005*
Step Inequality (cm)	4.5±3.0	2.6±1.7	-2.38	0.017*
Weight bearing on amputated side (%)	45.3±1.9	47.2±3.4	-2.03	0.042*
Ambulation index score (0-100)	72.5±3.2	82.3±4.9	-2.82	0.005*
Ambulation activities (sec)				
Sit down on a chair	36.4±8.0	31.4±2.2	-1.88	0.059
Stand up from a chair	32.8±8.1	28.1±5.7	-2.82	0.005*
Descending stairs	15.5±1.7	12.1±1.2	-2.67	0.007*
Ascending stairs	17.3±1.3	14.3±0.9	-2.84	0.004*
Descending slopes	19.6±1.3	12.9±1.2	-2.85	0.005*
Ascending slopes	21.0±1.2	13.3±0.9	-2.82	0.005*
Walking over obstacles	2.3±0.7	1.1±0.3	-2.76	0.006*

* p<0.05. KJ: Knee joint.

Table 3. Comparison of balance, physiological cost index, and patient satisfaction.

	Mechanic KJ X±SD	Hydraulic KJ X±SD	z	p
Balance (Berg Scale) (0-56)	21.0±7.4	49.0±9.9	-2.97	0.003*
Physiological Cost Index (beats/min)	34.9±8.8	27.8±7.6	-2.80	0.005*
Patient satisfaction (SATPRO) (0-45)	24.4±4.9	38.7±4.4	-2.81	0.005*

* p<0.05. KJ: Knee joint. SATPRO: Satisfaction with Prosthesis Scale.

Table 4. Comparison of quality of life outcomes.

	Mechanic KJ X±SD	Hydraulic KJ X±SD	z	p
Nottigham Health Profile				
Energy Level (EL) (0-100)	19.8±8.4	8.7±4.6	-1.21	0.225
Pain (P) (0-100)	14.2±4.9	5.1±3.0	-1.99	0.046*
Emotional Reaction (ER) (0-100)	10.2±5.6	8.2±3.6	-0.40	0.686
Sleep (S) (0-100)	10.6±5.6	0.0±0.0	-1.60	0.109
Social Isolation (SI) (0-100)	18.4±8.4	17.8±6.6	-0.10	0.916
Physical Abilities (PA) (0-100)	17.9±6.1	12.1±6.0	-0.89	0.373
Total Score(0-600)	91.1±28.6	51.9±12.5	-2.66	0.008*

* p<0.05. KJ: Knee joint.

Although our methods differed from theirs, gait speed also was greater, no asymmetrical gait were obtained in our study. It was thought that hydraulic knee joint was very effective on gait in the trans-femoral amputees according to our results in accordance with the literature.

Easy adaptation to normal gait activities and closer gait to normal have been provided because patients feel much more comfortable according to gait parameters with the hydraulic knee joint prosthesis instead of the mechanical one. The features of the hydraulic knee joint (i.e. adaptability to the normal gait pattern during the phases of gait on the basis of the flexion and extension degrees, and fifteen degree knee flexion control following the heel contact with the ground)[12] enable ergonomically balanced strides.[20]

According to the literature, better results, especially in terms of speed of gait, have been obtained in gait trials performed using different pneumatic and hydraulic knee joints.[19,20] Schmalz et al. investigated the activity of climbing up and down stairs biomechanically in trans-femoral amputees who used hydraulic knee joints. They found that the time taken to complete this activity was very close to the values of the control group when using mechanic knee joints.[21] Our results that subjects have no difficulties in climbing stairs with the hydraulic knee joint and they finish the activity in a shorter time when compared to when using the mechanical knee joint were similar to the results reported by Schmalz et al. It was thought that this similarity resulted from the better compatibility of the hydraulic knee joint to the activity.[20-22] Hafner et al, stated that with the hydraulic knee joint activities like stair and slope climbing, and walking over obstacles can be performed more successfully, and falling down was less frequent compared with the use of mechanical knee joint. This resulted from the joint's high adaptability to many activities at the same time.[23] Similarly, the success of the trans-femoral amputees in performing daily ambulation activities with hydraulic knee joints has been reported by Klute et al.[24]

Burger et al. reported that standing up from a sitting position with different prosthetic components is a difficult activity for trans-femoral amputees, and therefore, the control of the knee joint can be done more successfully with a hydraulic knee joint. They also examined sitting down and standing up from the chair and the time taken to perform that activity was recorded.[9] Patients emphasized that they sometimes lost their balance while sitting down and standing up from the chair and they had to control the knee joint continuously by focusing on it during this activity. However, the results stated that with the use of the hydraulic knee joint the patient could perform the activity in a shorter period of time. The results obtained from our assessments of ambulation activities (such as stair ascending-descending and inclined walking) and the success in the activities of balance was found to be similar to those other studies when we used a hydraulic knee joint. It was thought that these benefits were of a well-tolerated acrylic socket design properly fitting the stump and of hydraulic knee joint providing better mechanical alignment.

Vrieling et al, reported that negotiating obstacles is more difficult for trans-femoral amputees than the trans-tibial ones. Balance has to be better, otherwise falling due to hitting the obstacle will occur more frequently.[25] In our study the subjects were more successful with the hydraulic knee joint for this activity. Negotiating obstacles is an instantaneous activity and it requires balance and weight transfer onto one extremity for a short time. It is possible that subjects can perform this activity without any loss of balance when using the mechanical knee joint, but in order to prevent the knee joint from going into flexion they have to control it. This problem results from the impossibility of applying enough weight to the knee joint. However, by the use of the hydraulic knee joint when negotiating obstacles was performed in a shorter time because balance and weight bearing were better.

In our study energy consumption was calculated using the PCI. Subjects consumed less energy when they walked six minutes using trans-femoral prostheses with hydraulic knee joints. It was thought that the lower PCI obtained in our study with the hydraulic knee joint was due to easy adaptation of this joint, having a wider range of motion than the mechanic knee joint, to the gait phases.[11] Subjects stated that the hydraulic knee joint was compatible with the healthy knee joint while they were walking with the hydraulic knee joint for six minutes. They did not get tired during the gait, perceiving it as a natural extremity. The PCI values reflected this situation and the results were positive for the hydraulic knee joint.

In our study life quality was investigated by the NHP and no differences were found in sub-parameters except for pain. However, the total quality of life score was higher with the use of hydraulic knee joint. Pain of the subjects was resulted from chronic tiredness due to the incompatibility of the socket and the stump. The subjects faced no problems with the new acrylic sockets regarding the compatibility of the stump and socket. This resulted in an increase in the positive responses about pain, which is a sub-parameter in the life quality survey.

In the literature, there are many studies that show that life quality is affected by prosthetic components, prosthetic type and aesthetic appearance.[10,16,27] In addition, our results indicate that the quality of life of subjects depends on the knee joint. Even though we evaluated life quality by a different survey, it was thought that life quality was affected from performing the ambulation activities in a shorter period and easily with the use of the hydraulic knee joint. Similarly, when Hafner et al. examined mechanic and hydraulic knee joints with respect to life quality by SF 36 in trans-femoral amputees, they found that amputees were more successful with the hydraulic knee joint in climbing stair and slope activities, which have a great effect on their quality of life.[23]

The satisfaction levels of subjects were evaluated using a prosthesis satisfaction survey and it was noteworthy that subjects who used hydraulic knee joint prostheses with new sockets were satisfied in terms of function, aesthetic appearance, and comfort. The common result is that with higher socket compatibility and better aesthetic appearance greater satisfaction is obtained.[5,10,28] In addition to the satisfaction of subjects using hydraulic knee joint prostheses in terms of comfort, it is also necessary to emphasize that subjects are much more motivated when using hydraulic knee joint prostheses, which are more technological than mechanic ones and this also affected their level of satisfaction.

Hydraulic knee joint was used and socket changing was fitted in our study. The same socket at old socket type (polyester) was fitted the patients but, it was used with a different material (acrylic). It was thought that socket change and different material usage affected only harmony between the stump and socket. The difference in NHP pain scores could be the socket and the material change. In terms of patient satisfaction, it was believed that hydraulic knee joint and new socket design affected the total score on the SATPRO consisted from different parts such as functionality, aesthetic and comfort.

Our results showed that utilization of a hydraulic knee joint together with an adequate prosthetic training had positive effects on gait, functional activities, and energy consumption in amputees with high activity levels although the number of patients included in the study was not large enough to allow us to generalize the results for trans-femoral amputees.

The effects of the usage of hydraulic knee joint use on energy consumption and satisfaction were studied, and it was shown that energy consumption decreased, subjects' satisfaction increased, and gait was near normal by the use of hydraulic knee joint in trans-femoral amputees. Mechanical knee joints are used widely in Turkey because they are both economical and functional. However, in patients with high mobility level, hydraulic knee joints could be used in order to be more active.

In conclusion, we assumed that our results were parallel with the relevant literature and may stimulate interest in conducting further work in the field of prosthetic training. We thought that our study which evidences that proper selection of prosthetic components according to the patients functional level has positive effects on quality of life, gait pattern and energy expenditure, may outline a framework for a further guideline designed to describe prosthetic prescription for both private and governmental insurance systems in Turkey.

ACKNOWLEDGEMENT

This study was funded by Hacettepe University Scientific Research Unit (06.D02.401.001).

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