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Analysis of Time-Distance and Kinematic Gait Parameters Between Unilateral Trans-Tibial Amputees and Healthy Subjects

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국문요약

하퇴의지 착용자와 정상성인 보행간의 시간-거리 및 운동형상학 변수 분석

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본 연구는 하퇴의지 착용자와 정상 성인간의 시간-거리, 운동형상학 변수를 조사하고 비교하기 위하여 실시하였다. 연구 대상자는 외상으로 인한 하퇴 절단자로서 내골격식 하퇴의지를 착용하고 독립적으로 보행이 가능한 20명과 연령, 신장으로 짝짓기한 대조군(matched control group) 20명이 참여하였다. 보행분석은 Vicon Clinical Manager Software (VCM)를 내장한 PC에 5개의 카메라가 연결되어 있는 Vicon 512 Motion Analysis System (MAS, Oxford Metrics Inc.)을 이용하였다. 하퇴의지 착용군의 단하지 지지시간이 정상 성인군에 비해 유의하게 짧았으며($p<.05$), 하퇴의지 착용군에서 슬관절의 신전이 증가되었으며 족관절의 저측굴곡이 감소되었다($p<.05$). 하퇴절단자들의 보행개선을 위해서는 하퇴절단자 개인의 보행능력에 알맞은 부품의 선택, 체계적인 보행훈련 및 평가, 보행능력 향상을 위한 근력강화 프로그램 등 체계적인 재활훈련 프로그램이 필요한 것으로 사료된다. 본 연구는 연구대상자의 수가 제한되어 있으므로 연구의 결과를 일반화하기에는 제한점이 있으나, 향후 편측 하퇴절단자의 보행연구에 대한 기초 자료로 사용될 수 있을 것이라고 생각된다.

핵심단어: 거리-시간 변수; 보행 분석; 운동형상학 변수; 하퇴 의지.

Introduction

Amputation refers to incomplete or complete loss of extremity resulted from trauma, vascular, or congenital musculoskeletal diseases and is performed to improve function. Prosthesis is used to substitute the amputated limb and to provide lost function and cosmetic appearance (Kottke et al, 1982). Prosthesis is generally classified as upper limb prosthesis and lower limb prosthesis, and lower limb prosthesis can be classified in terms with amputation level. Trans-tibial prosthesis refers to artificial lower limb for amputation between ankle joint and knee joint (Shurr and Cook, 1990).

Gait analysis is used for clinical decision making tool for musculoskeletal and neurological diseases, evaluation after treatment, evaluation for prosthesis and orthosis, and biomechanical research. It has been utilized to measure time-distance, kinematic and kinetic parameters, electromyography, and metabolic energy expenditure (Wall et al, 1976).

The gait of healthy subject is characterized by high degree of symmetry between time-distance parameters for both legs. The highest values for symmetry observed are for the step length (ratio: .98), the stance time (ratio: .96), and the double-limb support time (ratio: .90), (Hirokawa, 1989). Therefore, rehabilitation procedures of amputees are necessary to provide normal lower limb function, i.e. symmetrical gait (Isakov et al, 1996).

A efficient prosthesis enables trans-tibial amputees to ambulate freely. Nevertheless, gait analysis in trans-tibial amputees has shown conspicuous leg asymmetry, as reflected by various measured gait parameters (Bagley and Skinner, 1991; Isakov et al, 1997). Trans-tibial amputation is responsible for biomechanical change such as muscles, bones, and joint missing (Viton et al, 2000). Consequently, the quality of gait of trans-tibial prosthesis user depends on pain-free stump, optimal socket fit, optimal lower limb alignment, and physical and psychological status (Isakov et al, 2000).

The purposes of this study were to compare the gait characteristics of trans-tibial amputees with those of matched healthy subjects and to provide basic gait data of unilateral trans-tibial amputees.

Methods

Subjects

Twenty trans-tibial subjects, all male, participated voluntarily for the study. The inclusion criteria for subjects were: 1) The cause of amputation is from external trauma excluding diabetic and peripheral blood vessel diseases. 2) All subjects have pain-free stump without any skin graft. 3) Subjects were able to ambulate independently without assistive devices. 4) Subjects wear endoskeletal prosthesis. Endoskeletal prosthesis consisted of patellar-tendon bearing (PTB) socket, cuff suspension, single axis foot-ankle assembly. Age-and sex-matched twenty healthy subjects were recruited from Seoul Veterans Hospital employees and visitors

Table 1. General characteristics of subjects (N=40)

Characteristics	Amputee group (n=20)	Healthy group (n=20)
Age (year)	58.06±7.37*	57.00±3.57
Weight (kg)	67.40±8.52	69.57±12.58
Height (㎝)	167.80±6.66	168.87±5.20
Stump length (㎝)	15.73±3.39	
Time since prosthesis application (year)	26.33±13.32	

*Mean±SD

who ambulated independently without musculoskeletal or neurological diseases.

Procedures

The past medical history, height, weight, bilateral leg length, and bilateral anthropometric data were collected for all subjects. Vicon 512 Motion Analysis System[1] including five cameras was used with Vicon Clinical Manager Software (VCM) for gait analysis. The calibration procedures were performed to correct any errors that possibly occur during data collection. The 2.5 ㎝ spherical reflective markers were applied to designated anatomic structures bilaterally such as sacrum, anterior superior iliac spine, lateral knee joint, lateral thigh, lateral condyle of tibia, lateral tibia, second metatarsal head, and posterior calcaneus as indicated in test protocol. All subjects were asked to ambulate with self-selected comfortable speed.

Statistical analysis

Independent t-test was used to determine statistical significance between trans-tibial amputees and healthy subjects. Statistical Program for Social Science (SPSS)/WIN 10.0 was used, and significance level was .05.

1) MAS, Oxford Metrics Inc.

Results

Subjects

The average age of 20 trans-tibial amputees was 58.06±7.37 years, weight was 67.40±8.52 kg, and height was 167.80±6.66 ㎝. The average age of matched healthy men was 57.00±3.57 years, weight was 69.57±12.58 kg, and height was 168.87±5.20 ㎝. Characteristics of subjects were presented in Table 1.

Time-distance parameter comparison

The cadences in trans-tibial amputee group and in healthy group were 97.76±26.29 steps/min and 109.80±10.61 steps/min, respectively. The walking velocity in trans-tibial amputee group and healthy group were 1.07±.20 ㎧ and 1.09±.19 ㎧, respectively. The stride length in trans-tibial amputee group was 1.23±.12

m that was longer than 1.18±.12 m in healthy group. The single support time in trans-tibial amputee group was 33.81% compared with 36.51% in healthy group. The double support time in trans-tibial amputee group and healthy group were 30.90% and 27.78±3.73, respectively (Table 2).

Kinematic parameter comparison

The maximal range of hip flexion in trans-tibial amputee group and healthy group were 33.73±7.79° and 29.67±5.80°, respectively. The maximal range of hip extension in trans-tibial amputee group and healthy group were -14.84±9.27° and -14.87±3.16°, respectively. The maximal range of knee flexion was 58.92±8.66° in trans-tibial amputee group that was higher than 57.34±6.04° in healthy group. The maximal range of knee extension was -4.87±6.14° in trans-tibial amputee group that was also higher than 4.07±2.88° in healthy group. The maximal range of ankle dorsiflexion was 15.43±8.20° in trans-tibial amputee group compared with 16.05±2.22° in healthy group. The range ankle plantar flexion was -1.11±6.54° in trans-tibial amputee group compared with 6.82±4.62° in healthy group (Table 3).

Table 2. Time-distance parameter comparison

Parameters	Amputee group	Healthy group	
Cadence (steps/min)	97.76±26.29*	109.80±10.61	.117
Walking velocity (m/s)	1.07±.20	1.09±.19	.820
Stride length (m)	1.23±.12	1.18±.12	.336
Single support time (% cycle)	33.81±4.35	36.51±2.08	.042
Double support time (% cycle)	30.90±5.57	27.78±3.73	.083

*Mean±SD

Table 3. Kinematic parameters in sagittal plane (unit: °)

Parameters		Amputee group	Healthy group	
Hip joint	Flexion	33.73±7.79*	29.67±5.80	.105
	Extension	-14.84±9.27	-14.87±3.16	.992
Knee joint	Flexion	58.92±8.66	57.34±6.04	.568
	Extension	-4.87±6.14	4.07±2.88	.000
Ankle joint	Dorsiflexion	15.43±8.20	16.05±2.22	.780
	Plantar flexion	-1.11±6.54	-6.82±4.62	.011

*Mean±SD

Discussion

Time-distance parameters

Breakey (1976) reported that stance phase of trans-tibial amputation side was shorter than that of healthy side and that single limb support time of trans-tibial amputation side and healthy side was 37% and 43%, respectively. Robinson et al (1977) suggested that walking speed, cadence, and stride length were lower in trans-tibial amputee compared with healthy side resulting in asymmetrical gait. Isakove et al (2000) also reported that step and step time between amputated and healthy side was asymmetrical.

The cadence of healthy subjects in our study was consistent with previous reports of 116.0~127.9 step/min (Perry, 1992; Gage, 1983; Skinner, 1985). The cadence of trans-tibial amputee group ranged from 92.3~106.0 step/min (Barth et al, 1992; Huang et al, 2000; Isakov et al, 2000) that is also consistent or decreased value with cadence of trans-tibial amputee group in our study. Though cadence between trans-tibial amputee group and healthy subjects was different, statistically significant difference was not found. It is thought that significant significance was not shown because standard deviation of our study was rather variable.

The gait velocity of healthy subjects reported ranged from 1.19 m/s to 1.43 m/s (Gage, 1983; Perry, 1992; Skinner, 1990). The gait velocity of healthy subjects in our study was decreased compared with that of previous studies. The gait velocity of trans-tibial amputees was reported from 1.07 m/s to 1.11 m/s (Colborne et al, 1992; Robinson et al, 1977; Sandra, 2000) that was consistent with that of our study. However, the difference between two groups was not statistically different.

The stride length of healthy subjects in previous studies (Skinner and Effeney, 1985; Winter, 1991) ranged from 1.48 m to 1.51 m that was higher than the result of our study. The stride length of trans-tibial amputees ranged from 1.32 m to 1.44 m (Robinson, 1977; Water et al, 1976; Barth et al, 1992; Huang et al, 2000), and the results of our study was lower compared with those of previous studies. These differences can be explained by the fact that the stride length is dependent on height and the increased stride length can contribute to walking velocity (Colborne et al, 1992). Therefore, the lower value of stride length in our study resulted from the lower height of our subjects compared with that of previous studies. The previous studies suggested that the stride length of trans-tibial amputees was shorter than that of healthy limb. This was contradictory to our results of present study. This discrepancy might be resulted from the fact that the different characteristics of prosthetic foot and mechanical alignment such as limited dorsiflexion of ankle joint and weight bearing status played a role in different condition.

The single support time was shorter in trans-tibial amputee group compared with that of healthy group, and the double support time was longer in trans-tibial group. This accounts for the fact that trans-tibial amputees have difficulty in bearing weight in amputated side. In addition, other factors such as mechanical properties and decreased proprioceptive input of prosthetic foot.

The walking velocity was not significantly different between two groups. However, cadence in trans-tibial amputee group was lower compared with that of healthy group. This suggests that compensatory mechanism by increasing stride length occurred for lower cadence in trans-tibial amputees.

Kinematic parameters

The maximal range of ankle joint in trans-tibial amputees was less than that of healthy subjects. This decreased range can be explained that eccentric contraction of plantar flexion during loading response and extension of metatarsophalangeal joint during terminal and pre-swing phase could occur in prosthetic foot.

The maximal range of knee joint in trans-tibial amputees was greater than that of healthy subjects. This increased range can be thought as a compensatory mechanism for limited ankle joint ROM in trans-tibial amputees. In normal gait pattern, knee joint shows stereotypical pattern, i.e. flexion-extension-flexion during stance phase. Instead of this normal gait pattern, the gait of trans-tibial amputees demonstrated excessive hyperextension during stance phase. This hyperextension was explained by compensatory mechanism especially from initial contact to mid-stance to improve stability and weigh bearing capability (Barth et al, 1992). Another factor that contribute to hyperextension of knee joint is the duration since the prosthesis was donned since the amputation. The average donning duration of trans-tibial amputee recruited in this study was 26 years that is enough time to get accustomed to hyperextended knee.

The maximal range of hip joint in trans-tibial amputees was greater than that of healthy subjects. This increased hip joint range can also be the results of compensation mechanism to increase stride length in amputated side.

The limitations of this study were as follows: 1) Since the data were collected on a even surface with Vicon 512 Motion Analysis System, real terrain environment in which the subjects ambulate was not considered. 2) All trans-tibial subjects ambulated wearing their own shoes. Since prostheses were aligned to subjects' own shoes, different shoe condition could affect the results of this study. 3) The kinematic parameters in frontal and transverse planes and kinetic parameters were not compared between two groups.

Conclusion

Previous studies suggested that gait of trans-tibial amputees is characterized by asymmetry. The purpose of this study is to confirm this asymmetrical gait pattern of trans-tibial amputees and to present basic data for asymmetrical gait pattern. The time-distance, kinematic parameters were investigated and compared between trans-tibial amputee group and matched healthy group. The motion analysis system was used to collect the data. The conclusion was as follows:

1. The single limb support time of trans-tibial amputee group was significantly lower than that of healthy group ($p<.05$).
2. The maximal range of knee extension in trans-tibial amputee group was higher than that of healthy group, but the maximal range of ankle plantar flexion in trans-tibial amputee group was lower than that of healthy group ($p<.05$).
3. There was a tendency in trans-tibial amputee group to hyperextend the knee to increase stability during weight bearing.

Rehabilitation program including selection of proper prosthetic items, systematic gait training, and muscle strengthening program is necessary to allow amputees to improve symmetric gait pattern. Although the limited numbers of amputees were recruited in this study, the results of this study can be used as a basic gait characteristic data for trans-tibial amputees. Further studies are needed to analyze complete kinematic and kinetic parameters for trans-tibial amputees.

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