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Original Article

Gait analysis of elderly women after total knee arthroplasty

Aenon Lee, PT, MSc[1)], Junhyuck Park, PT, MSc[1)], Seungwon Lee, PT, PhD[2)*]

1) Department of Physical Therapy, The Graduate School of Sahmyook University, Republic of Korea
2) Department of Physical Therapy, Sahmyook University: 815 Hwarangro, Nowon-gu, Seoul 139-742, Republic of Korea

Abstract. [Purpose] The purpose of this study was to investigate ability and muscle activities of elderly women after total knee arthroplasty (TKA) and compare them with those of healthy ones. [Subjects and Methods] Fifteen female patients with TKA due to advanced degenerative arthritis of the measured on knee joint and 19 healthy elderly females participated. Tibiofemoral angles of TKA patients were using a gait analysis system anterioposterior X-rays of the weight-bearing knee. The knee flexion angle and gait parameters were measured. Muscle activities and prolongation time were EMG system. The gait of the treated limb of each participant was evaluated in three consecutive trials at fast speed and comfortable speed. [Results] The knee flexion angle %stance phase, stride length, step length, speed, cadence, and gait cycle significantly decreased at both the fast speed and comfortable speeds, and the onset and duration time of rectus femoris activity was significantly increased at the comfortable speed in the TKA group. [Conclusion] In conclusion, elderly women who received TKA showed decreased gait ability and muscle activity compared to the healthy elderly women.

Key words: Arthroplasty, Gait, Electromyography

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INTRODUCTION

The extension of life expectancy leads to an aging society and an increase in the aged population, most of whom are considerably affected by a joint disease called osteoarthritis[1)]. Osteoarthritis not only causes pain, but results in physical disablement and lowering of quality of life[2, 3)], and those who suffer from severe osteoarthritis usually receive total knee arthroplasty (TKA)[4)].

It is reported that the 15% of patients who receive TKA suffer from various degrees of pain ranging from a light pain to severe pain for one year, although this problem is not found in radiography[5, 6)]. In addition, since an artificial joint is transplanted into the knee, the propulsive force to go forward is reduced, and mechanical stress occurs[7)]. As a result, biomechanical changes arise in the knee joint[8)].

Generally, the gait pattern of the aged is found to be similar to the gait of pattern patients with TKA. This gait pattern shows a decrease in the ability to move the body forward[9)] leading to weakness of the joints of the lower limb that causes functional limitations, and the functional weakness retrains knee extension and knee flexion[10)]. The aged show weakness of the rectus femoris and their knee movement changes during the gait. In addition, when they are walking, their stride length tends to be short, even though there is not a big change in their gait pattern, and they develop a stable gait pattern by lengthening the double support phase time and shortening the single support phase time[9)].

Many researchers have been studying kinematic gait characteristics of TKA patients according to their locomotion. Walsh et al.[11)] reported that the gait speed of patients with TKA is 22–16% less than the normal. McClelland et al.[12)] revealed that TKA patients' range of motion in a gait cycle is relatively lower than that of normal, and that the accompanying changes in flexion are extension moment patterns were related to abnormal activation of the rectus femoris and hamstrings[13)]. The muscle contraction of TKA patients has been studied using electromyography[14)], and TKA patients have been studied at more than 6 months after TKA for mid-and long-term evaluation[15)].

However, most previous studies were conducted using kinematic gait analysis and electromyography analysis of the patients, separately, so it is difficult to understand TKA patients' overall gait abilities, and to find studies which have evaluated the immediate post-operative effects of TKA.

Therefore, this study investigated the gait ability and muscle activities of early post-operative TKA patients to establish the changes in their gait speed through comparison with healthy elderly females in order to quantitatively, and thereby analyze their gait function.

*Corresponding author. Seungwon Lee (E-mail: swlee@syu.ac.kr)

SUBJECTS AND METHODS

Subjects

The subjects of this study were 15 elderly females who received TKA and 19 healthy elderly females. All of the study subjects fully understood the purpose and content of this study and agreed to participate in the tests conducted in this study. This study was approved by the Institutional Review Board of Sahmyook University. The elderly female patients who received TKA were those who were diagnosed with osteoarthritis and underwent TKA less than one month earlier whose surgical status didn't affect their gait or balance, who were able to walk more than 10 m without the help of others, and whose tibiofemoral angle (TFA) was 3–8° of valgus alignment in a radiographic evaluation. The healthy elderly female participants were those who had never received an orthopedic operation.

Methods

The radiographs of the TKA patients were examined prior to the measurement of their gait. TFA was measured on anterior-posterior X-rays of the weight-bearing knee joint. TFA is a representative index of the structural result after TKA. The optimal TFA after the surgery is reported to be 3–8° of valgus alignment[16]. To measure TFA, two lines were drawn on the distal one-third of the femur and on the highest one-third of the tibia on a radiograph. The lines were extrapolated and the angle of their intersection was measured as TFA[17].

For the measurement of gait ability and knee joint flexion angle, a gait analyzer (OptoGait, Microgate S.r.l, Italy, 2010) was used. Parallel bars emit and receive infra-red light, and the analyzer detects the gait of a subject walking between the bars, recording data on time and space variables. Video data is recorded on a web-cam (Logitech Webcam Pro 9000), and is used to synchronize the data with gait events. The recorded time and space variable data was processed using the OptoGait program (Version 1.5.0.0, Microgate S.r.l, Italy, 2010). The equipment was calibrated prior to the test, and reflective markers were attached along the axis of the lower limb to measure knee joint flexion angle in the stance phase.

For the measurement of muscle activity and prolongation time, a Zerowire electromyography (Noraxon Inc, USA, 2008) was used. Surface electrodes were attached to the rectus femoris, hamstrings (biceps femoris and semitendinosus), tibialis anterior, and medial gastrocnemius to measure muscle activity[18]. The electromyography signals recorded by surface electrodes were amplified, digitally sampled at 1,000 Hz, and saved on computer using the software application Myoresearch XP (Noraxon, USA, 1998). Five channels and a foot switch were used, and recorded data were pre-processed with notch filtering at 50 Hz to remove noise and band pass-filtered between 10 and 450 Hz.

Subjects wore comfortable clothing to walk. The gait analyzer consists of two transmitter and receiver bars 3 m in length and a web-cam. The two bars were installed in parallel, 1 m apart. Reflective markers 15 mm in diameter were attached to the central part of the greater trochanter, lateral side of femur and talus[19]. The study subjects walked barefoot for the tests[20]. For the measurement of knee joint angle in the sagittal plane, 2 web-cams were installed to the front and side of the motion direction to record gait motion.

The muscle activity was measured using an EMG system while the study subjects walked. For prevention of measurement errors, electrodes were attached to muscles after the skin had been abraded with sandpaper and cleaned with an alcohol swab. The electrode attachment points were: one half the distance between the patella and iliac spine on the front side of the femur for the rectus femoris; three quarters of the distance between the knee joint and malleolus for the tibialis anterior; the middle point between ischial tuberosity and tibia, and 3 cm to the inside for the semitendinosus; two thirds the distance from the posterior side of the knee to the greater trochanter for the biceps femoris; and 2 cm above and 35% part inward from the middle line of the distal knee joint for the medial gastrocnemius. The distance between the surface electrodes was 2 cm in all cases.

For the reference voluntary contraction (RVC), electromyography was measured for 5 seconds in consideration of the influence of each study subject's personal characteristic. The raw data were converted to root mean square values. The 5-second measurement was performed three times and the average value was calculated. For the mean activity, the first one second and last one second of data were excluded so that only the middle three seconds were in the calculation. For gait muscle activity, the gait test at a normal speed and the gait test at a fast speed were conducted three times each and the mean value was calculated. The electromyography signals recorded in specific phases from the loading response phase of the affected side and the entire swing phase were used after conversion to %RVC[21]. %RVC is the percentage ratio of the RVC that is based on the peak or mean value observed during the specific activity.

For the investigation of muscle duration time of the rectus femoris, hamstrings (biceps femoris and semitendinosus), tibialis anterior, and medial gastrocnemius after TKA, a foot switch was attached to the heel of the surgically operated lower limb before study subjects walked. The 2.0 seconds of the most stable electromyography during the period from time of the heel-off to the time of heel-strike was used to calculate the mean value and standard deviation (SD) of the electromyography signal amplitudes. Using Di Fabio's[22] determination method, the first EMG trace to rise above the threshold value (the mean value of the baseline period +3SD) for more than 25 μs after the start of walking, was analyzed. For the measurement of prolongation time, a foot switch was attached to the heel of the surgically operated lower limb, and a gait test at a normal speed and a gait test at a fast speed were each conducted three times. The mean activity of each test was calculated after the deduction of the starting time and end time.

For all statistical analyses SPSS ver. 18.0 was used. The means and standard deviations were calculated. The subjects' general characteristics and experimental results were tested for normality using the Shapiro-Wilk test. For the comparison of differences between the two study groups, the independent t-test was performed. The statistical significance level used in all analyses was 0.05.

Table 1. Comparison of subjects' general characteristics

	TKA elderly	Healthy elderly
Age (years)	62.3 ± 4.5	63.1 ± 3.7
Hight (cm)	161.1 ± 3.5	159.7 ± 2.4
Weight (kg)	56.4 ± 5.5	55.4 ± 3.2
TFA (°)	7.71 ± 1.06	Not applicable

The values are presented as mean ± SD.
TKA: total knee arthroplasty; TFA: tibiofemoral angle

Table 2. Gait parameters and knee joint flexion angle in the stance phase of each group at the different gait speeds

		TKA elderly	Healthy elderly
Gait velocity (m/s)	NS	0.50 ± 0.14	0.75 ± 0.18*
	FS	0.68 ± 0.25	1.04 ± 0.25*
Gait cycle (s)	NS	1.59 ± 0.31	1.25 ± 0.25*
	FS	1.36 ± 0.41	0.97 ± 0.21*
Stance phase (%)	NS	64.13 ± 9.89	68.06 ± 6.74
	FS	65.2 ± 8.31	64.51 ± 5.84
Cadence (step/min)	NS	82.39 ± 20.30	106.98 ± 27.10*
	FS	110.10 ± 43.89	127.86 ± 25.27
Step length (cm)	NS	33.1 ± 6.21	41.74 ± 6.42*
	FS	36.97 ± 8.84	48.15 ± 7.22*
Stride length (cm)	NS	73.17 ± 12.14	85.37 ± 10.76*
	FS	75.17 ± 14.99	97.55 ± 14.26*
Loading response (°)	NS	9.73 ± 2.73	15.80 ± 2.78*
	FS	12.00 ± 3.02	17.42 ± 8.15*
Mid stance (°)	NS	6.92 ± 2.19	8.65 ± 2.96
	FS	9.07 ± 3.01	5.66 ± 2.27*
Terminal stance (°)	NS	14.26 ± 4.62	22.45 ± 7.16*
	FS	16.47 ± 5.91	24.38 ± 6.74*
Pre swing (°)	NS	30.92 ± 6.28	42.77 ± 4.56*
	FS	36.03 ± 8.04	44.40 ± 9.37*

The values are presented as mean ± SD.
TKA: total knee arthroplasty; NS: normal speed; FS: fast speed
*$p<0.05$: significant difference between TKA elderly and Healthy elderly

Table 3. Muscle activities of each group at the different gait speeds

		TKA elderly	Healthy elderly
RF	NS	19.1 ± 11.7	27.7 ± 16.7
	FS	19.3 ± 8.9	24.1 ± 12.6
ST	NS	26.5 ± 17.6	29.0 ± 17.5
	FS	21.9 ± 10.7	23.5 ± 12.9
BF	NS	18.8 ± 8.2	20.9 ± 13.3
	FS	19.0 ± 8.1	20.5 ± 12.1
MG	NS	25.4 ± 15.9	28.2 ± 14.0
	FS	23.7 ± 14.2	30.4 ± 13.2
TA	NS	28.3 ± 12.5	28.3 ± 14.1
	FS	20.4 ± 9.4	25.3 ± 14.5

The values are presented as mean ± SD.
TKA: total knee arthroplasty; NS: normal speed; FS: fast speed; RF: rectus femoris; TA: tibialis anterial; ST: semitendinosus; BF: biceps femoris; MG: medial gastrocnemius

RESULTS

Fifteen TKA patients and 19 healthy elderly women were evaluated. No significant differences were found in the general characteristics of either groups (Table 1).

For gait ability at the normal gait speed, there were significant differences in walking speed, gait cycle, cadence, step length, and stride length between the TKA patient group and the healthy elderly group ($p<0.05$), and in the case of the gait capability at a fast speed, there were significant differences in walking speed, gait cycle, step length, and stride length between the TKA patient group and the healthy elderly group ($p<0.05$).

Regarding knee joint flexion angle, at the normal gait speed, there were significant differences in the loading response at the end stance phase and during the entire swing phase between the patient group and the healthy group ($p<0.05$), and at the fast gait speed, there were significant differences in the loading response in the mid stance phase, at the end stance phase, and during the entire swing phase between the TKA patient group and the healthy elderly group ($p<0.05$) (Table 2).

There were no significant differences in the muscle activities of the groups at both the normal gait speed and the fast gait speed (Table 3).

Regarding the muscle activation times, at the normal gait speed, there were significant differences in the start time of tibialis anterior activity and the end time of rectus femoris activity ($p<0.05$), and at the fast gait speed, there were significant differences in the end times of rectus femoris activity and gastrocnemius activity ($p<0.05$) (Table 4).

DISCUSSION

In this study, radiographs of the TKA patients and of the healthy elderly females were evaluated, and then gait characteristics of the lower limb, knee joint flexion angle in the stance phase, muscle activity duration and muscle activity change were compared at different gait speeds.

In this study, gait showed statistically significant differences between the elderly females who underwent the TKA and the healthy elderly females ($p<0.05$). Benedetti et al.[23] reported that the gait ability of TKA patients showed a significant reduction in stride length, gait cycle, and cadence compared to healthy subjects ($p<0.0001$), and that the duration of their stance phase was significantly more than that of healthy subjects ($p=0.003$). Ouellet and Moffet[24] reported that speed, cadence and stride length significantly decreased within the first 2 months after the surgery ($p<0.05$), and that gait cycle lengthened. This was similar to the gait characteristic of the TKA patients within the first month after the surgery found in this study.

Table 4. Muscle activity duration of each group at the different gait speeds

		TKA elderly	Healthy elderly	TKA elderly	Healthy elderly	TKA elderly	Healthy elderly
		Onset time (s)		Cessation time (s)		Duration time (s)	
RF	NS	2.00±0.36	2.01±0.05	2.59±0.22	2.45±0.14*	0.59±0.22	0.44±0.13*
	FS	1.99±0.02	2.00±0.00*	2.52±0.21	2.51±0.18	0.54±0.20	0.51±0.18
ST	NS	1.98±0.42	2.00±0.00	2.71±0.34	2.57±0.22	0.54±0.31	0.61±0.24
	FS	1.99±0.24	2.00±0.01	2.52±0.25	2.49±0.18	0.61±0.20	0.57±0.18
BF	NS	2.04±0.17	2.01±0.02	2.62±0.38	2.48±0.27	0.73±0.34	0.57±0.22
	FS	1.99±0.19	2.00±0.01	2.50±0.25	2.40±0.19	0.53±0.25	0.50±0.18
MG	NS	2.09±0.22	2.14±0.19	2.53±0.30	2.55±0.28	0.57±0.39	0.47±0.28
	FS	2.01±0.07	2.08±0.11*	2.59±0.47	2.53±0.14	0.52±0.24	0.40±0.19
TA	NS	1.99±0.02	2.01±0.02*	2.53±0.31	2.61±0.24	0.44±0.29	0.41±0.27
	FS	1.99±0.02	2.03±0.14	2.60±0.21	2.59±0.18	0.58±0.46	0.45±0.20

The values are presented as mean ± SD.
TKA: total knee arthroplasty; NS: normal speed; FS: fast speed; RF: rectus femoris; TA: tibialis anterial; ST: semitendinosus; BF: biceps femoris; MG: medial gastrocnemius
*p<0.05: significant difference between TKA elderly and Healthy elderly.

In the comparison of knee joint flexion angles at different gait speeds between the TKA patients and the healthy elderly females, at both the normal gait speed and fast gait speed, the TKA patient group's angles were lower than those of the healthy elderly group in all phases of the loading response ($p<0.05$), and during the entire swing phase ($p<0.05$). According to Benedetti et al.[23], the angle in the loading response phase was 16.7° for the healthy subjects and 10.4° for TKA patients, a significant reduction ($p=0.001$), and the angle in the entire swing phase was 38.2° for the healthy subjects and 33.7° for the TKA patients, a significant reduction in the knee joint flexion angle ($p=0.04$). This result was similar to this study's result, although we did not find a significant difference in the angle between the healthy group and the patient group in the mid stance phase at a normal gait speed. Schipplein and Andriacchi[25] emphasized the interaction between muscle and ligament in terms of a structure to stabilize the knee joint dynamically in the mid stance phase. TKA patients actively contract the muscles and this causes muscle loss. For this reason, excessive action of the ligament is considered to affect the mid stance phase. McClelland et al.[20] showed that mechanical changes in knee are significantly reduced, in a comparison of healthy subjects and TKA patients walking at normal and fast gait speeds. The present study result showed that the faster the speed was, the greater the increase in the knee joint angle, but that the TKA patient's angles were significantly smaller than those of healthy subjects. Therefore, the present result is similar to the result of McClelland et al[20]. Saari et al.[19] reported that there was a significant difference in gait changes at a fast gait speed, and Tew et al.[26] reported that the knee flexion angle after TKA increased by 17%. That was either because, compared to normal cartilage prior to TKA, friction between metal and plastic increased after the surgery, or because there was a habitual gait type in the stance phase of stiff knee gait to alleviate pain in the stance phase prior to the surgery[27].

The motion range on a sagittal plane of TKA is first under the control of muscle[28]. During the weight loading phase, the knee joint generates an external flexion moment at about 15 degree of flexion status, and against the moment, contracts quadriceps muscle contracts generating an internal extension moment[29]. It was reported that TKA patients' co-contracted muscles for a while during the stance phase, and that the co-contraction time of the rectus femoris and hamstrings lengthened[23]. According to the results of this study, the rectus femoris activity duration of the TKA patients was 0.59 s at the normal gait speed and 0.54 s at fast gait speed, and that of the healthy elderly's was 0.44 s at the normal gait speed and 0.51 s at the fast gait speed. Thus, the TKA patients rectus femoris activity duration was longer that of than the healthy elderly ($p<0.05$). We consider that the long co-contraction of muscles around the knees is a compensatory action to help the knees make a larger mechanic adjustment in the stance phase.

Regarding the muscle activity difference resulting from surgery, there were no statistically significant differences in the activities of rectus femoris muscle, biceps femoris, semitendinosus, tibialis anterior, and medial gastrocnemius between the groups. The TKA patients' muscle activities were lower than those of the healthy elderly, but there were no significant differences in the muscle activities even though the duration increased abnormally. However the muscle activity of the rectus femoris, of the TKA patients was less than that of the healthy elderly females at both the normal and fast gait speeds. This result was similar to previous studies that TKA surgery reduces the muscle activity of the rectus femoris[30].

This study had several limitations. The sample size was small so it is difficult to generalize the results to all TKA patients. The early functional evaluation of the TKA patients was meaningful. This study had a cross-sectional design which makes it difficult to compare with other long-term studies directly. A longitudinal study may be necessary for comparison.

The results of this study indicate that there were differences in gait speed, step length, stride length, and cadence between the elderly females who received TKA surgery and the healthy elderly females ($p<0.05$), and that abnormal contraction of the rectus femoris muscle caused a reduction in the range of motion of the knee joint. Therefore, we consider that it is necessary to provide a clinical approach to reduce the abnormal gait of TKA patients, and that the primary treatment goal for functional activity should be to restore the patients' muscle strength, balance, and the range of motion of the knee joints.

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