



Post-operative Physical Performance Factors Associated With Gait Speed in Patients Surgically Treated for Hip Fracture: A Cross-Sectional Study

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Objective To determine post-operative physical performance factors associated with gait speed in patients surgically treated for hip fracture.

Methods Cross-sectional data from 59 patients (16 males and 43 females; mean age, 79.2±9.1 years) who underwent hip fracture surgery were enrolled. Patients completed a 10-meter walk test (10MWT) to assess gait speed. Additional physical performance tests included the Timed Up and Go test (TUG), the Berg Balance Scale (BBS), maximum voluntary isometric contraction (MVIC) of the knee extensors and flexors on the operated and non-operated sides as well as of the hip abductors (all tested using air-resistance weight machines), and analysis of spatio-temporal gait parameters at about 6 weeks after hip surgery.

Results Bivariate analyses revealed a significant positive correlation between the post-operative 10MWT and the post-operative TUG, age, swing phase duration, and gait cycle duration along with a significant negative correlation between post-operative BBS score, MVIC of the knee extensors and flexors on the operated and non-operated sides, MVIC of the hip abductors, and cadence and stance phase duration. Linear regression analyses revealed that the post-operative TUG ($\beta=0.85$, $p<0.01$), gait cycle duration ($\beta=0.17$, $p=0.02$), and osteoporosis ($\beta=-0.18$, $p=0.02$) were associated with the post-operative 10MWT.

Conclusion The presence of osteoporosis, post-operative balance, and isometric muscle strength in the operated and non-operated legs were statistically associated with post-operative gait speed early after hip fracture surgery.

Keywords Hip fractures, Gait speed, Muscle strength, Balance, Rehabilitation

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INTRODUCTION

Hip fracture is a major traumatic injury in older adults, often caused by falling. Hip fracture is often associated with age-related bone mineral loss and an increase in the number of comorbidities, which increase the risk of falling. According to the World Health Organization, the number of patients with hip fracture worldwide is expected to increase to 6.3 million by 2050 (from 1.7 million in 1990) [1]. In Asian countries such as South Korea and Japan, where the older population is increasing rapidly, the prevalence of hip fracture is expected to rise annually. Indeed, the number of hip fracture patients in South Korea increased steadily from 47,760 in 2008 to 68,023 in 2012; 83% of fractures occur in patients older than 50 years [2].

Hip fractures in older adults can have serious consequences, including increased morbidity and mortality, functional deficit, and increased healthcare costs. Functional decline after hip fracture increases the need for help with activities of daily living (ADL) by more than 50% [3]. Thus, most patients with hip fracture require surgery to improve mobility, independence, and quality of life. Unfortunately, the majority of patients with hip fracture have not regained pre-fracture functional status at 1 year post-surgery [4,5]. According to a previous study, only about 50% of patients regain their pre-injury independent walking ability at 1 year after hip surgery; most have difficulties with ADL [6].

Recovery of gait function after hip surgery is a major concern for both physiatrists and patients and is considered a major factor for estimating prognosis with respect to post-operative physical function. Thus, intensive post-operative rehabilitation after hip fracture surgery focuses on improving basic mobility and gait. Additionally, organized rehabilitation strategies are also important because they can prevent further falls.

In a previous study, Ingemarsson et al. [7] suggested that among the many gait parameters, gait speed has been used most often to describe recovery of gait function in older adults. Gait speed is an attractive outcome measure for hip fracture because it is easy to measure, requires no special equipment, and measures a physiological impairment [8]. Physical therapy and rehabilitation programs may improve mobility in patients with impaired gait. Follow-up measurements of gait speed could

be used to monitor treatment outcomes. Several authors have suggested that measuring gait speed is important to evaluate patient improvement during different stages of the rehabilitation program [9-12]. The relationship between knee extensor strength and physical performance is well established in hip fracture patients. A decline in knee extensor muscle strength is correlated with problems in mobility factors such as gait speed and balance [13]. Increase of strength may, through correlation, be explained by peripheral changes in the skeletal muscle mass and quality [14].

Additionally, our authors wanted to study gait speed and other related factors, which were selected from existing studies. For example, Lamb et al. [15] reported that lower extremity strength, balance, and pain are associated with gait speed in hip fracture patients at 1 week post-surgery, and Whitehead et al. [8] suggested a significant correlation between gait speed, the Modified Barthel Index, the London Handicap Scale, the Berg Balance Scale (BBS), the Falls Efficacy Scale, and the Activities-specific Balance Confidence Scale at 4 months post-surgery. Madsen et al. [16] found a statistical relationship between age, height, weight, number of months since fracture, isokinetic quadriceps muscle strength, and maximum walking speed in patients who developed a hip fracture 3-36 months previously.

However, few studies have examined the correlation between gait speed and objective performance status, particularly during the early period after hip fracture surgery. Identification of post-operative physical performance factors that affect gait speed early after hip fracture surgery is vital. Particularly, it is important to identify the important factors at this time, at the cross-sectional study point of this study, when the acute treatment is complete and the patient is discharged home.

This study hypothesized that there are correlations between objective performance-based physical function and gait function early after hip fracture surgery. Therefore, this study aimed to identify objective performance-based physical parameters that affect gait performance by evaluating gait speed, which is closely related to walking ability.

MATERIALS AND METHODS

Participants

This was a cross-sectional study evaluating the correlation between objective performance-based physical function and gait function early after hip fracture surgery.

The study enrolled 59 older adults (16 males and 43 females; mean age, 79.2 ± 9.1 years) with hip fracture who underwent surgery at the Department of Orthopedic Surgery in Jeju National University Hospital between December 2014 and December 2016 (Fig. 1). Patients were transferred to the rehabilitation department approximately 4 weeks after surgery. Patients who met the following inclusion criteria were enrolled: (1) hospitalized between December 2014 and December 2016; (2) aged ≥ 65 years; (3) acute unilateral hip fracture—femoral neck, intertrochanteric, subtrochanteric, femur (mid-shaft or trans-cervical); and (4) the ability to walk independently with or without an ambulatory aid. Surgical treatments included total hip arthroplasty, bipolar hemiarthroplasty, and closed reduction and internal fixation. The exclusion criteria were: (1) other causes of operation than hip fracture (infection, arthritis, loosening of the insert, or avascular necrosis); (2) acetabular fracture, peri-implant fracture, or pathological fracture due to tumor; and (3) multiple fractures. Fortunately, no patient experienced delirium during the study period. The study protocol was approved by the Institutional Review Board of Jeju National University Hospital (No. 2018-01-002). Written informed consents were obtained.

Rehabilitation protocol

All patients underwent an intensive rehabilitation program that included progressive resistance strengthening exercises, gait training, and balance training. No weight-bearing exercise was performed for 1 week after surgery; from the second week after surgery, a standard rehabili-

tation program was implemented in the Department of Orthopedic Surgery, starting with tilt table exercises and proceeding to p-bar gait training. Progressive resistance strengthening exercises were started from 10%–20% of each patient's one-repetition maximum (1RM). About 2 weeks after surgery, the following intensive rehabilitation program was implemented at the Department of Rehabilitation. Progressive resistance strengthening exercises comprised concentric leg extension, leg curls, and hip abduction using air-resistance machines (HUR Co., Kokkola, Finland). Exercises (3 sets of 15 repetitions) were performed at 30% of the 1RM. Each session lasted 30 minutes. The 1RM was reassessed every week; the resistance was increased gradually until the patients could perform 60% of their 1RM for 3 sets of 10 repetitions. Gait training began on a tilt table and/or parallel bars. If the patient could complete about 10 rounds on the parallel bars without rest, they progressed to the Alter G anti-gravity treadmill (Model M320; Alter G Inc., Fremont, CA, USA). Subjects started to walk at a comfortable speed with 50% body weight support (BWS) and progressed by adjusting gait speed and/or the degree of BWS. Balance training was performed using a THERA-Trainer apparatus (Medica Medizintechnik GmbH, Hochdorf, Germany). All rehabilitation programs were performed twice per day (gait training was performed daily, and strength exercises and balance training were performed on alternate days), 5 times per week for 2 weeks. All sessions were supervised by physical therapists.

Outcome measures

All patients were assessed by a skilled physical therapist approximately 4 to 5 weeks post-surgery. Physical performance function tests included the 10-meter walk test (10MWT), the Timed Up and Go test (TUG), the BBS, the 1RM of leg extension and leg curls on the operated and non-operated sides, and hip abduction. Instrumental analysis of gait-related spatio-temporal parameters was also performed.

10MWT

This test is a simple gait assessment to determine walking speed. The time taken to walk 10 m is measured using a stopwatch and walking speed is calculated by dividing the distance covered by the time taken (m/s) [17]. The higher the value of 10MWT, the slower the gait speed

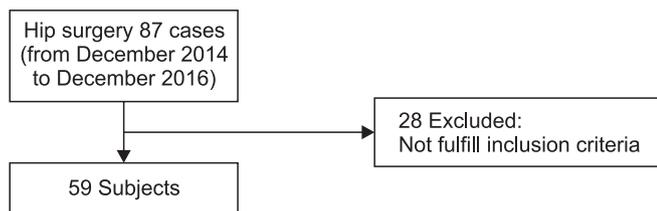


Fig. 1. Flowchart of the study subjects.

value.

TUG

The TUG started from a seated position in a standard armchair (seat height=46 cm). The patient was instructed to get up from the chair, walk 3 m (with their usual walking aid) to a line of colored tape placed on the floor, turn around, return to the chair, and sit back down. The stopwatch started when the patient's buttocks lifted from the seat and stopped when the buttocks retouched the seat [18]. The higher the TUG value, the lower the gait speed value.

BBS

The BBS is an objective measurement of dynamic balance obtained while performing 14 functional tasks. Items on the BBS are scored on a scale of 0 to 4 points, with a maximum summed score of 56; higher scores indicate better balance and functional independence with respect to activities tested. The Korean version of the BBS has been validated [19].

Measurement of lower limb strength

Isometric strength of the knee extensors, knee flexors, and hip abductors was measured using a stationary dynamometer (HUR Co.) which uses a hydraulically powered lever arm that measures the isometric contraction of these muscle groups. The subject sat on a chair while grasping the handles on both sides. In extension, the knee angle was 120° (full extension=180°) and the hip angle was 110°. In flexion, the knee angle was 140° and the hip angle was 110°. In abduction, the angle between the two legs was 15° and the hip angle was 110°. The subject was instructed to exert maximal force during extension, flexion, and abduction and to maintain the position for 5 seconds. Two trials were conducted for each leg, with 2-minute rest in between. When measuring knee extensor and flexor strength, the two legs were measured separately. Measurements always began with extension of the right knee. When measuring hip abductor strength, both legs were measured simultaneously.

Gait analysis

Spatio-temporal variables related to gait were measured using a validated 24 wireless inertial sensing device (G-Walk; BTS Bioengineering S.p.A., Milan, Italy). A semi-

elastic back-belt device worn around the waist measured acceleration values for the three anatomical axes (anteroposterior, mediolateral, and vertical). Patients were instructed to walk 8 m at a comfortable speed as naturally as possible. The gait data were collected and transmitted via Bluetooth to a personal computer where they were processed using the BTS G-Walk system (dedicated software that measures gait variables such as gait speed, cadence, stride length, duration of gait cycle, stance phase, swing phase, and double support) [20].

- Cadence (stride/min): number of steps per minute during normal gait.
- Stride length (m): the distance between two successive placements of the same foot.
- Duration of gait cycle (s): the duration that begins when one foot makes contact with the ground and ends when that same foot contacts the ground again.
- Stance phase (s): the gait phase that lasts from heel strike to toe off, which accounts for 60% of a single gait cycle.
- Swing phase (s): non-weight phase of gait; double support means both feet in contact with the floor.

Statistical analysis

All statistical analyses were performed using SPSS version 20.0 for Windows (SPSS Inc., Chicago, IL, USA). All variables were subjected to descriptive statistical analysis. A t-test analysis was performed to identify the difference between the sexes. Pearson correlation analysis was calculated to assess relationships between gait speed and objective performance-based physical function values. Multivariate regression analysis using a backward selection linear regression model was used to determine which objective performance-based physical function variables and demographic variables including body mass index and comorbidities best explain gait speed early after hip fracture surgery. We controlled the age and sex variables. Moreover, the backward stepwise linear regression analysis was performed by using the values derived from the significant result by bivariate analysis. Additionally, correlation and regression analyses were performed for both sexes. A p-value of <0.05 was considered statistically significant.

Table 1. Demographic and disease-related characteristics of the subjects

Variable	Total (n=59)	Male	Female
Sex		16 (27.1)	43 (72.9)
Age (yr)	79.2±9.1	72.3±10.7	81.7±6.9*
Height (cm)	156.0±9.2	165.3±8.3	152.6±6.8**
Weight (kg)	54.9±9.5	63.0±10.1	51.9±7.4*
BMI (kg/m ²)	22.5±3.1	23.0±2.7	22.3±3.2
Time from surgery to RM transfer (day)	15.5±7.9	14.9±2.8	15.7±9.1
Duration at RM (day)	17.4±5.3	16.7±4.3	17.7±5.7
Fracture side			
Right	29 (49.2)	8 (50.0)	21 (48.8)
Left	30 (50.8)	8 (50.0)	22 (51.2)
Fracture site			
Femur neck	9 (15.3)	3 (18.8)	6 (14.0)
Intertrochanteric	33 (55.9)	10 (62.5)	23 (53.5)
Subtrochanteric	8 (13.6)	1 (6.3)	7 (16.3)
Femur mid shaft	3 (5.1)	0 (0.0)	3 (7.0)
Transcervical	6 (10.2)	2 (12.5)	4 (9.3)
Operation type			
THRA	9 (15.3)	3 (18.8)	6 (14.0)
BPHA	8 (13.6)	3 (18.8)	5 (11.6)
ORIF	42 (71.2)	10 (62.5)	32 (74.4)
Comorbidities			
Hypertension	37 (62.7)	10 (62.5)	27 (62.8)
Diabetes mellitus	11 (18.6)	4 (25.0)	7 (16.3)
Spine disease	3 (5.1)	0 (0.0)	3 (7.0)
Osteoporosis	46 (78.0)	8 (50.0)	38 (62.8)*
Dementia	6 (10.2)	0 (0.0)	6 (14.0)
VAS	2.3±0.4	2.3±0.5	2.2±0.4
Ambulatory aid			
Use			
Walker	42 (71.2)	10 (62.5)	32 (74.4)
Quadri-cane	12 (20.3)	4 (25)	8 (18.6)
Non-use	4 (6.8)	2 (12.5)	2 (4.7)

Values are presented as number of cases (%) or mean±standard deviation.

BMI, body mass index; RM, repetition maximum; THRA, total hip replacement arthroplasty; BPHA, bipolar hemiarthroplasty; ORIF, open reduction internal fixation; VAS, visual analog scale.

*p<0.05, **p<0.01.

RESULTS

Baseline demographic and disease-related characteristics are presented in Table 1. The mean RM admission duration was 17.4±5.3 days. Of the 59 patients enrolled, 33 (55.9%) had an intertrochanteric fracture; 42 (71.2%) underwent closed reduction and internal fixation. Ad-

ditionally, 45 (76.3%) had osteoporosis and 6 (10.2%) had dementia. The mean visual analog score (VAS) was only about 2.3. Among the patients, 55 were using ambulatory aids and only 4 could walk independently. There were no infections, wound-related complications, nerve injuries, or any other post-operative problems.

Post-operative evaluation of physical performance after hip fracture surgery

The average scores/results for the post-operative objective performance-based physical function test are presented in Table 2. In subgroup analysis in terms of the sexes, male had faster TUG ($p<0.01$), gait cycle duration ($p=0.04$), and cadence ($p=0.04$); higher BBS ($p=0.07$); and greater 1RM of non-surgical knee extensor ($p<0.01$), 1RM of surgical knee flexor ($p<0.01$), and 1RM of non-surgical knee flexor ($p<0.01$) than females.

Correlation between gait speed and objective performance-based physical function after hip fracture surgery

Bivariate analyses revealed a significant positive correlation between gait speed and the TUG ($r=0.85$, $p<0.01$), gait cycle duration ($r=0.49$, $p<0.01$), and swing phase duration ($r=0.35$, $p<0.01$), but a negative correlation with BBS ($r=-0.69$, $p<0.01$), MVIC of the knee extensors on the operated side ($r=-0.35$, $p<0.01$), MVIC of the knee extensors on the non-operated side ($r=-0.40$, $p<0.01$), MVIC of the knee flexors on the operated side ($r=-0.44$,

$p<0.01$), the 1RM of the knee flexors on the non-operated side ($r=-0.41$, $p<0.01$), the 1RM of the hip abductors ($r=-0.25$, $p=0.04$), cadence ($r=-0.53$, $p<0.01$), and the duration of the stance phase ($r=-0.26$, $p=0.02$) (Table 3). In the abovementioned data, positive and negative signs indicate the direction of association with the gait speed. Positive direction is expressed when gait speed becomes faster as each variable increases, and the negative direction is expressed when each variable becomes smaller as gait speed becomes faster.

In the bivariate analyses of both sexes, gait speed showed a significant correlation with the TUG ($p<0.01$), BBS ($p<0.01$), 1RM of non-surgical knee extensor ($p=0.04$), cadence ($p<0.01$), and gait cycle duration ($p=0.02$) in males and with the TUG ($p<0.01$), BBS ($p<0.01$), 1RM of surgical knee extensor ($p=0.03$), 1RM of surgical knee flexor ($p<0.01$), 1RM of non-surgical knee flexor ($p=0.04$), cadence ($p<0.01$), gait cycle duration ($p<0.01$), and swing phase duration ($p<0.01$) in females. Additionally, the VAS score was not statistically significant in the entire group and in each group of males and females.

Table 2. The postoperative evaluation of physical performance after hip fracture surgery

Variable	Total (n=59)	Male	Female
10MWT (s)	24.7±13.0	17.6±7.3	30.9±13.7*
TUG (s)	28.1±14.7	20.5±12.4	30.9±14.7*
BBS	40.8±11.2	44.9±10.0	39.2±11.4*
Strength parameters			
MVIC of surgical knee extensor (Nm)	27.9±12.6	34.2±17.3	25.6±9.5
MVIC of non-surgical knee extensor (Nm)	44.4±15.5	55.9±17.4	40.1±12.4*
MVIC of surgical knee flexor (Nm)	18.3±8.5	22.6±7.7	16.6±8.2*
MVIC of non-surgical knee flexor (Nm)	22.6±9.8	28.3±9.8	20.4±9.1*
MVIC of hip abductor (Nm)	40.1±16.8	46.4±25.0	37.9±12.1
Gait parameters			
Cadence (steps/min)	39.9±13.9	45.7±11.5	37.7±14.2*
Stride length (m)	1.1±0.2	1.1±0.2	1.1±0.2
Gait cycle duration (s)	1.8±1.0	1.5±0.9	1.9±1.1*
Stance phase duration (% of gait cycle)	63.5±3.4	63.5±2.6	63.6±3.6
Swing phase duration (% of gait cycle)	36.4±3.9	36.5±2.6	36.4±4.3
Double support duration (% of gait cycle)	27.5±3.4	13.4±2.6	13.9±3.6
Single support duration (% of gait cycle)	36.0±3.6	36.6±2.6	35.8±3.9

Values are presented as mean±standard deviation.

10MWT, 10-meter walk test; TUG, Timed Up and Go test; BBS, Berg Balance Scale; MVIC, maximum voluntary isometric contraction.

* $p<0.05$.

Table 3. Correlation between gait speed and objective performance-based physical function after hip fracture surgery

	Correlation coefficients (r)		
	10MWT	Male	Female
TUG (s)	0.85**	0.91**	0.84**
BBS	-0.69**	-0.86**	-0.65**
Strength parameters			
MVIC of surgical knee extensor (Nm)	-0.35**	0.26	-0.33*
MVIC of non-surgical knee extensor (Nm)	-0.40**	-0.51*	-0.27
MVIC of surgical knee flexor (Nm)	-0.44**	-0.12	-0.43**
MVIC of non-surgical knee flexor (Nm)	-0.41**	-0.46	-0.32*
MVIC of hip abductor (Nm)	-0.25*	-0.38	-0.28
Gait parameters			
Cadence (steps/min)	-0.53**	-0.63**	-0.46**
Stride length (cm)	0.03	-0.29	0.10
Gait cycle duration (s)	0.49**	0.58*	0.45**
Stance phase duration (% of gait cycle)	-0.26*	-0.16	-0.30
Swing phase duration (% of gait cycle)	0.35**	0.16	0.40**
Double support duration (% of gait cycle)	-0.22	-0.39	-0.24

10MWT, 10-meter walk test; TUG, Timed Up and Go test; BBS, Berg Balance Scale; MVIC, maximum voluntary isometric contraction; VAS, visual analog scale.

*p<0.05, **p<0.01.

Linear regression analysis with 10MWT

Linear regression analyses identified the post-operative TUG result ($\beta=0.78$, $p<0.01$), osteoporosis ($\beta=-0.18$, $p=0.02$), and gait cycle duration ($\beta=0.17$, $p=0.02$) to be associated with the post-operative 10MWT result (adjusted $R^2=0.77$) (Table 4). In the linear regression analysis of data obtained from males, the TUG result ($\beta=0.82$, $p<0.01$) and osteoporosis ($\beta=-0.22$, $p=0.03$) were factors correlated with the post-operative 10MWT result (adjusted $R^2=0.92$). In the analysis of data obtained from females, the TUG result ($\beta=0.80$, $p<0.01$), osteoporosis ($\beta=-0.26$, $p<0.01$), and cadence ($\beta=-0.21$, $p<0.01$) were factors correlated with post-operative 10MWT result (adjusted $R^2=0.78$).

DISCUSSION

This study evaluated the association between objective performance-based physical function and gait speed early after hip fracture surgery. The results demonstrated a significant association between gait speed and balance and between gait speed and muscle strength of the surgical and non-surgical legs during the early period after hip fracture surgery. Presence of osteoporosis

Table 4. Postoperative factors correlated with gait speed by multivariate linear regression analysis

Outcome/independent predictor	Standardized β	p-value	Adjusted R^2
Total			
TUG (s)	0.78	<0.01	0.77
Osteoporosis	-0.18	0.02	
Gait cycle duration (s)	0.17	0.02	
Male			
TUG (s)	0.82	<0.01	0.92
Osteoporosis	-0.22	0.03	
Female			
TUG (s)	0.80	<0.01	0.78
Osteoporosis	-0.26	<0.01	
Cadence (step/min)	-0.21	0.01	

also affected gait speed. As described in results, in the subgroup of both sexes, gait speed showed a significant correlation with many factors. Even in the differences between the sexes, the results were similar to those of the whole group. In a previous study, Thingstad et al. [21]

determined that gait speed is a strong indicator of gait function. Morri et al. [22] reported that the gait speed is impaired on discharge after hip surgery; therefore, physiotherapy protocols conducted during the acute phase after surgery should focus on this to improve the patient's walking ability and efficiency.

To analyze the causes of these results, this study selected the main factors that were similar to those found in a previous sample of older people, supporting the view of a more universal gait model [23]. Kline et al. [24] showed that lower extremity strength and balance stability predict gait speed after hip fracture. Moreover, this study considered the effects of hip surgery on walking such as gait speed, shortening and decreased cadence, increased double support time, decreased step length, and increased single support asymmetry during gait analysis in another study [25]. In another study, Whitehead et al. [8] suggested that patients with hip fracture had slower gait speed, which may reflect lower limb strength and lower balance ability.

Based on our prior research, in this study, we have attempted to identify factors that affect gait function, including those associated with a poor outcome, by objective measurement of the physical function of patients early after hip fracture surgery. Among the many different gait parameters, previous studies have suggested that gait speed may be the most useful parameter for assessing the functional effects of hip fracture surgery and for monitoring recovery.

In this study, we found that the mean gait speed of our cohort at about 4 to 5 weeks post-hip fracture surgery was 0.4 m/s. This appears to be an improvement over a study of 304 patients that reported a mean gait speed of 0.47 m/s after 12 months [26]. Unfortunately, we found that the gait speed of our cohort was much slower than that of age-matched healthy controls from another study; further, the mean gait speed for older adults in this age group was about 1.0 m/s [27-29]. This result suggests that more intensive therapeutic strategies may be necessary to facilitate the recovery of gait function to the levels observed in healthy people of a comparable age. Another notable point of this study, as seen in the bivariate analyses of both sexes, was that gait speed showed a significant correlation between the TUG, BBS, and the 1RM of the non-surgical knee extensor; cadence; and gait cycle duration in males and the TUG, BBS, and 1RM of the surgi-

cal knee extensor; the 1RM of the surgical knee flexor; the 1RM of the non-surgical knee flexor; cadence; gait cycle duration; and the swing phase duration in females. Apart from the common factors among the analyzed variables, the difference was seen in the 1RM measurement. In case of the knee extensor and gait speed mentioned above, it can be analyzed as follows. Decline in knee extensor muscle strength is correlated with mobility problems such as gait speed, balance, and stair-climbing ability in hip fracture patients [14]. In the previous study, muscle strength of the man was stronger than that of the woman [30]. Woodward et al. [31] suggested that men performed better in tests of knee extensor strength than women after 4 weeks of the exercise program in patients with hip fractures; however, these between-sex differences in knee extension strength were no longer evident once adjustments were made for body weight.

Most importantly, this study shows that the post-operative TUG can predict post-operative gait speed. Moreover, in the bivariate analyses of both sexes, gait speed showed a significant correlation with the TUG.

A possible explanation for our results is that performance in the TUG depends on a combination of walking ability, lower limb strength, and balance (owing to the sit-to-stand and turn-around components); therefore, it involves neuromuscular components such as strength, agility, and balance. Taking this finding into consideration, our results have important clinical implications in that balance training combined with strengthening of the lower limbs could improve gait speed, thereby increasing functional mobility in hip fracture patients. In a previous study, Freter and Fruchter [18] reported a good linear relationship between gait time and the TUG in an orthopedic rehabilitation population comprising older adults, which was similar to our results. Nankaku et al. [32] found that the TUG is a useful predictor of ambulation ability at 6 months post-surgery.

The BBS score was associated strongly with post-operative gait speed. In the bivariate analysis, it was also a significant factor affecting both sexes. These results show that balance ability is also sufficiently related to gait speed. Several previous studies support these findings. Whitehead et al. [8] showed a significant relationship between the BBS score and gait speed of patients with hip fracture and Radosavljevic et al. [33] reported a significant relationship between the BBS score and functional

status.

Here, this study used both the TUG and BBS to evaluate balance and function, and both tests showed a significant correlation with gait speed, indicating that balance training soon after surgery improves gait speed.

Isometric strength of the hip abductors was associated with post-operative gait speed. Leijendekkers et al. [34] found that hip abduction strength on the operated side was on average 23% lower than that on the non-operated side, and Kubota et al. [35] demonstrated that hip abductor muscle strength was significantly correlated with the peak hip abduction moment; indeed, a reduced hip abduction moment after hip fracture may result in an abnormal hip motion, which could slow gait speed. Kline et al. [24] found that the strength of the hip extensors and hip abductors on the operated side predicted gait speed after hip fracture. Based on these studies, analysis of hip abduction is of significance. However, in this study, we could not measure the strength of the abductors in each hip individually due to the design of the machine (although the strength of the quadriceps and hamstrings was measured separately). Additionally, the isometric strength of the knee extensors and flexors was associated with gait speed. In previous studies, we found that the strength of the quadriceps and hamstrings muscles on the operated and non-operated sides showed a significant correlation with gait speed. Lamb et al. [15] suggested that leg extensor power (LEP) on the operated side is the main factor that accounts for differences in gait speed. LEP on the non-operated side was also a predictor, but that result only accounted for 22% of correlation. Portegijs et al. [36] suggested that weaker lower extremity power of the non-fractured leg at 1 week post-surgery correlated significantly with slower gait speed and stair-climbing speed and predicted poorer mobility at 12 weeks. Moreover, cross-sectional analyses suggested that a large asymmetrical difference in lower extremity power was associated with slow stair-climbing speed at 1 and 13 weeks, but not with gait speed. The results of the above studies suggest that muscle strength in both legs is related to gait speed, and that differences between the two legs do not have a significant effect.

In the correlation analysis, VAS score was 2.3, which was not significantly correlated with gait speed. Perhaps, the pain medication at the time of the rehabilitation treatment showed that the pain was controlled smoothly.

In a similar study, Thingstad et al. [21] suggested that pain was not a significantly associated factor among the key variables following hip fracture.

Finally, the multivariate linear regression analysis showed that the TUG, osteoporosis, and gait cycle duration were significantly correlated with gait speed. Interestingly, in addition to the physical performance-based parameters we mentioned, osteoporosis was a significant factor for both sexes. Our results regarding gait speed were similar to those stated by Lindsey et al. [37], who reported an association between gait speed and bone mineral density (BMD). Dostanpor et al. [38] also suggested that gait speed was associated with low BMD or aging. This association implies that BMD management can also be an important factor in the rehabilitation process of patients with hip fracture.

This study has several limitations. First, it was a cross-sectional analysis without follow-up; therefore, it was not possible to monitor changes between baseline and follow-up. Because this study did not include pre-operative status due to cross-sectional analysis, it could not analyze the effect of pre-operative status on the present. Second, it may be difficult to estimate outcomes and reach a definitive conclusion because 4 to 5 weeks after hip fracture surgery is very early. Third, in this study, only the patients who met the gait criteria were included, so this criteria was not enough to represent all patients who underwent hip surgery. Fourth, this study did not address causal relationships as the study had a cross-sectional design without a control group. Finally, only 4 of 59 patients were capable of independent gait at the time of evaluation. The number of patients was unfortunately too small to perform a subgroup analysis. Therefore, further prospective and experimental studies are warranted to determine causal relationships between the variables studied herein and the effects of our intensive rehabilitation program.

In conclusion, we provide evidence of a significant association between gait speed and objective performance-based physical function. Additionally, balance ability and isometric muscle strength on both the operated and non-operated legs as well as the presence of osteoporosis were important explanatory factors for functional recovery after hip fracture surgery (as reflected by gait speed during the early post-operative period). These findings suggest that management of osteoporosis and rehabilitation

strategies that focus on improving balance and muscle strength in both legs (especially that of the hip abductors, knee extensors, and knee flexors) could help recovery of gait function during the early stages after hip fracture surgery.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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AUTHOR CONTRIBUTION

Conceptualization: Kim BR, Jeon YT. Methodology: Kim BR, Jeon YT, Han EY, Lee SY. Formal analysis: Kim BR, Jeon YT. Project administration: Kim BR, Jeon YT, Han EY, Nam KW, Lee SY, Park YG, Suh MJ, Kim JH. Visualization: Kim BR, Jeon YT, Han EY, Nam KW, Lee SY, Park YG, Suh MJ, Kim JH. Writing – original draft: Kim BR, Jeon YT. Writing – review and editing: Kim BR, Jeon YT. Approval of final manuscript: all authors.

REFERENCES

- World Health Organization. Osteoporosis: both health organizations and individuals must act now to avoid an impending epidemic. Geneva: World Health Organization; 1999.
- Choi ES, Shon HC, Kim YM, Kim DS, Park KJ, Lim CO, et al. Is the incidence rate of hip fractures still increasing in Korea? An epidemiologic study based on National Health Insurance Database. *J Korean Orthop Assoc* 2016;51:447-54.
- Gialanella B, Ferlucci C, Monguzzi V, Prometti P. Determinants of functional outcome in hip fracture patients: the role of specific neuropsychiatric symptoms. *Disabil Rehabil* 2015;37:517-22.
- Jette AM, Harris BA, Cleary PD, Champion EW. Functional recovery after hip fracture. *Arch Phys Med Rehabil* 1987;68:735-40.
- Mossey JM, Mutran E, Knott K, Craik R. Determinants of recovery 12 months after hip fracture: the importance of psychosocial factors. *Am J Public Health* 1989;79:279-86.
- Young Y, Brant L, German P, Kenzora J, Magaziner J. A longitudinal examination of functional recovery among older people with subcapital hip fractures. *J Am Geriatr Soc* 1997;45:288-94.
- Ingemarsson AH, Frandin K, Mellstrom D, Moller M. Walking ability and activity level after hip fracture in the elderly: a follow-up. *J Rehabil Med* 2003;35:76-83.
- Whitehead C, Miller M, Crotty M. Falls in community-dwelling older persons following hip fracture: impact on self-efficacy, balance and handicap. *Clin Rehabil* 2003;17:899-906.
- van den Akker-Scheek I, Stevens M, Bulstra SK, Groot-hoff JW, van Horn JR, Zijlstra W. Recovery of gait after short-stay total hip arthroplasty. *Arch Phys Med Rehabil* 2007;88:361-7.
- Hodt-Billington C, Helbostad JL, Vervaat W, Rogns-vag T, Moe-Nilssen R. Changes in gait symmetry, gait velocity and self-reported function following total hip replacement. *J Rehabil Med* 2011;43:787-93.
- Coulter CL, Scarvell JM, Neeman TM, Smith PN. Physiotherapist-directed rehabilitation exercises in the outpatient or home setting improve strength, gait speed and cadence after elective total hip replacement: a systematic review. *J Physiother* 2013;59:219-26.
- Kolk S, Minten MJ, van Bon GE, Rijnen WH, Geurts AC, Verdonschot N, et al. Gait and gait-related activities of daily living after total hip arthroplasty: a systematic review. *Clin Biomech (Bristol, Avon)* 2014;29:705-18.
- Lamoureux EL, Sparrow WA, Murphy A, Newton RU. The relationship between lower body strength and obstructed gait in community-dwelling older adults. *J Am Geriatr Soc* 2002;50:468-73.
- Roy MA, Doherty TJ. Reliability of hand-held dynamometry in assessment of knee extensor strength after hip fracture. *Am J Phys Med Rehabil* 2004;83:813-8.
- Lamb SE, Morse RE, Evans JG. Mobility after proximal femoral fracture: the relevance of leg extensor power, postural sway and other factors. *Age Ageing* 1995;24:308-14.
- Madsen OR, Lauridsen UB, Sorensen OH. Quadriceps

- strength in women with a previous hip fracture: relationships to physical ability and bone mass. *Scand J Rehabil Med* 2000;32:37-40.
17. Kang JH, Lee G, Kim KE, Lee YK, Lim JY. Determinants of functional outcomes using clinical pathways for rehabilitation after hip fracture surgery. *Ann Geriatr Med Res* 2018;22:26-32.
18. Freter SH, Fruchter N. Relationship between timed 'up and go' and gait time in an elderly orthopaedic rehabilitation population. *Clin Rehabil* 2000;14:96-101.
19. Jung HY, Park JH, Shim JJ, Kim MJ, Hwang MR, Kim SH. Reliability test of Korean version of berg balance scale. *J Korean Acad Rehabil Med* 2006;30:611-8.
20. Bugane F, Benedetti MG, Casadio G, Attala S, Biagi F, Manca M, et al. Estimation of spatial-temporal gait parameters in level walking based on a single accelerometer: validation on normal subjects by standard gait analysis. *Comput Methods Programs Biomed* 2012;108:129-37.
21. Thingstad P, Egerton T, Ihlen EF, Taraldsen K, Moenilssen R, Helbostad JL. Identification of gait domains and key gait variables following hip fracture. *BMC Geriatr* 2015;15:150.
22. Morri M, Natali E, Tosarelli D. At discharge gait speed and independence of patients provides a challenges for rehabilitation after total joint arthroplasty: an observational study. *Arch Physiother* 2016;6:6.
23. Lord S, Galna B, Rochester L. Moving forward on gait measurement: toward a more refined approach. *Mov Disord* 2013;28:1534-43.
24. Kline Mangione K, Craik RL, Lopopolo R, Tomlinson JD, Brenneman SK. Predictors of gait speed in patients after hip fracture. *Physiother Can* 2008;60:10-8.
25. Gausden EB, Sin D, Levack AE, Wessel LE, Moloney G, Lane JM, et al. Gait analysis after intertrochanteric hip fracture: does shortening result in gait impairment? *J Orthop Trauma* 2018;32:554-8.
26. Tinetti ME, Baker DI, Gottschalk M, Williams CS, Pollack D, Garrett P, et al. Home-based multicomponent rehabilitation program for older persons after hip fracture: a randomized trial. *Arch Phys Med Rehabil* 1999;80:916-22.
27. Leiper CI, Craik RL. Relationships between physical activity and temporal-distance characteristics of walking in elderly women. *Phys Ther* 1991;71:791-803.
28. Blanke DJ, Hageman PA. Comparison of gait of young men and elderly men. *Phys Ther* 1989;69:144-8.
29. Brach JS, VanSwearingen JM. Physical impairment and disability: relationship to performance of activities of daily living in community-dwelling older men. *Phys Ther* 2002;82:752-61.
30. Bohannon RW. Reference values for extremity muscle strength obtained by hand-held dynamometry from adults aged 20 to 79 years. *Arch Phys Med Rehabil* 1997;78:26-32.
31. Woodward LM, Clemson L, Moseley AM, Lord SR, Cameron ID, Sherrington C. Most functional outcomes are similar for men and women after hip fracture: a secondary analysis of the enhancing mobility after hip fracture trial. *BMC Geriatr* 2014;14:140.
32. Nankaku M, Tsuboyama T, Kakinoki R, Akiyama H, Nakamura T. Prediction of ambulation ability following total hip arthroplasty. *J Orthop Sci* 2011;16:359-63.
33. Radosavljevic N, Nikolic D, Lazovic M, Petronic I, Milicevic V, Radosavljevic Z, et al. Estimation of functional recovery in patients after hip fracture by Berg Balance Scale regarding the sex, age and comorbidity of participants. *Geriatr Gerontol Int* 2013;13:365-71.
34. Leijendekkers RA, Marra MA, Kolk S, van Bon G, Schreurs BW, Weerdesteyn V, et al. Gait symmetry and hip strength in women with developmental dysplasia following hip arthroplasty compared to healthy subjects: a cross-sectional study. *PLoS One* 2018;13:e0193487.
35. Kubota M, Uchida K, Kokubo Y, Shimada S, Matsuo H, Yayama T, et al. Changes in gait pattern and hip muscle strength after open reduction and internal fixation of acetabular fracture. *Arch Phys Med Rehabil* 2012;93:2015-21.
36. Portegijs E, Sipila S, Rantanen T, Lamb SE. Leg extension power deficit and mobility limitation in women recovering from hip fracture. *Am J Phys Med Rehabil* 2008;87:363-70.
37. Lindsey C, Brownbill RA, Bohannon RA, Ilich JZ. Association of physical performance measures with bone mineral density in postmenopausal women. *Arch Phys Med Rehabil* 2005;86:1102-7.
38. Dostanpor A, Dobson CA, Vanicek N. Relationships between walking speed, T-score and age with gait parameters in older post-menopausal women with low bone mineral density. *Gait Posture* 2018;64:230-7.