A Doctoral Dissertation

Bilateral Quadriceps Muscle Strength Correlate with Gait Speed and Endurance Early after Unilateral Total Knee Arthroplasty : A Cross-Sectional Study

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Bilateral Quadriceps Muscle Strength Correlate with Gait Speed and Endurance Early after Unilateral Total Knee Arthroplasty : A Cross-Sectional Study

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(Supervised by professor Bo Ryun Kim)

A thesis submitted in partial fulfillment of the requirement
for the degree of Doctor of Medicine

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This thesis has been examined and approved

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Department of Medicine

GRADUATE SCHOOL

JEJU NATIONAL UNIVERSITY

ABSTRACT

Bilateral Quadriceps Muscle Strength Correlate with Gait Speed and Endurance Early after Unilateral Total Knee Arthroplasty : A Cross-Sectional Study

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Background: The objective of this study was to determine the associations between objective performance-based physical function and gait function 1 month after unilateral total knee arthroplasty (TKA).

Methods: Cross-sectional data from one-hundred and ninety-five patients who underwent a unilateral primary TKA were enrolled in this study. Two weeks after TKA, all patients were transferred to the rehabilitation department and performed rehabilitation program for a 2-week period. The isometric knee extensor and flexor strength of both surgical and non-surgical knees, gait parameters, 6 minute walk test (6MWT), timed up-and-go (TUG) test, timed stair climbing test (SCT), knee flexion range of motion (ROM) and extension ROM of surgical knee, Western Ontario McMaster Universities Osteoarthritis Index (WOMAC) pain, stiffness, and functional levels, EuroQol five-dimensions (EQ-5D) questionnaire and visual analog scale (VAS) were assessed 1 month after TKA.

Results: In the bivariate analyses, postoperative gait speed had a significant positive correlation with postoperative peak torque (PT) of the extensor of the surgical knee ($r = 0.35$, $p < 0.001$), postoperative PT of the extensor of the non-surgical knee ($r = 0.43$, $p < 0.001$), postoperative PT of the flexor of the surgical knee ($r = 0.22$, $p < 0.001$), postoperative PT of the flexor of the non-surgical knee ($r = 0.21$, $p = 0.003$), 6MWT, cadence, stride length, and a significant negative correlation with TUG, SCT-ascent, SCT-descent, VAS, WOMAC pain, stiffness, and function score. The postoperative gait endurance had a significant positive correlation with postoperative PT of the extensor of the surgical knee ($r = 0.36$, $p < 0.001$), postoperative PT of the extensor of the non-surgical knee ($r= 0.49$, $p < 0.001$), postoperative PT of the flexor of the surgical knee ($r = 0.25$, $p < 0.001$), postoperative PT of the flexor of the non-surgical knee ($r = 0.34$, $p < 0.001$), gait speed, cadence, stride length, EQ5D, and a significant negative correlation with TUG, SCT-ascent, SCT-descent, VAS, and WOMAC pain, stiffness, and function scores. In the linear regression analyses, the postoperative PT of the extensors of the surgical knee ($\beta = 0.16$, $p = 0.04$) and non-surgical knee ($\beta = 0.27$, $p < 0.001$) and VAS ($\beta = -0.15$, $p = 0.03$) were factors associated with postoperative gait speed ($R^2 = 0.25$). The postoperative PT of the extensors of the surgical knee ($\beta = 0.15$, $p = 0.04$) and non-surgical knee ($\beta = 0.38$, $p < 0.001$) and VAS ($\beta = -0.13$, $p = 0.03$) were factors associated with postoperative endurance ($R^2 = 0.33$).

Conclusion: These results demonstrate that the quadriceps muscle strength of both surgical and non-surgical knees significantly associate with gait speed and endurance 1 month after unilateral TKA.

Key words: Quadriceps muscle, Gait, Arthroplasty, Replacement, Knee, Rehabilitation

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LIST OF ABBREVIATIONS

OA, osteoarthritis

TKA, total knee arthroplasty

WOMAC, Western Ontario McMaster Universities Osteoarthritis Index

VAS, visual analog scale

KSS, knee society score

ROM, range of motion

TENS, transcutaneous electrical nerve stimulation

RM, repetition maximum

LBPP, lower-body positive pressure

BW, body weight

PT, peak torque

6MWT, 6 minute walk test

TUG, timed up-and-go

SCT, timed stair climbing test

EQ-5D, EuroQol five dimension

BMI, body mass index

K-L, Kellgren-Lawrence

I. INTRODUCTION

Knee osteoarthritis (OA) is the leading cause of disability in elderly adults. Pain and swelling in the affected joint is commonly accompanied by decreased patient mobility, and can cause impairment to the activities of daily living and the quality of life (Peat G et al., 2001).

Total knee arthroplasty (TKA) is known as the most effective treatment for patients with severe end-stage knee OA. Over 600,000 TKAs are performed annually in the United States (AAOS, 2015). Patients who are waiting for their first TKA expect that the surgery will relieve the knee pain and improve gait function. However, despite improvements in knee pain and self-reported physical function after TKA, recent study has demonstrated that decrements in performance-based physical functions, including quadriceps strength and gait function, still persist and lead to disability (Noble PC et al., 2005). Despite successful TKA surgery, patients actually show an abnormal gait pattern for several years. For example, the recovery of a performance-based physical function such as gait speed improves only slowly, and gait speed limitations may persist 1 year after surgery (Nilsdotter AK et al., 2009).

Recovery of gait function has been a major concern of both physiatrists and patients, and is considered a main element for estimating postoperative function. Thus, recent intensive postoperative rehabilitation approaches after TKA have focused on improvements to basic mobility and gait function. However, although TKA surgery has a significant influence on the gait function of patients, there is no formal assessment indicator for walking ability or mobility included in the routine clinical assessment. There is also relatively limited evidence for a correlation between gait speed or endurance and objective performance status, especially during the early period after TKA.

A previous study on factors affecting the deterioration of gait function after TKA surgery reported primary correlations between gait speed and the Western Ontario McMaster

Universities Osteoarthritis Index (WOMAC) function score, and between gait speed and the knee pain score obtained with a visual analog scale (VAS) (Turcot K et al., 2013). Senden et al. also reported correlations between gait speed and VAS, and gait speed and Knee Society Score (KSS) (Senden R et al., 2011). These studies focused only on the relationship between gait speed and self-reported function status. Only a single study has reported that lower postoperative quadriceps strength and knee flexion range of motion are closely associated with gait speed at 4, 8, 12, and 16 weeks after surgery (Pua YH et al., 2016). However, to our knowledge, no studies have examined the correlation between gait endurance and objective performance factors.

Therefore, the aim of this study was to find the objective performance-based physical function affecting gait performance by evaluating gait speed and endurance, which are closely related to walking ability, and to then determine the postoperative rehabilitation strategies that could lead to improvements in the functional capacity of patients.

II. METHODS

Study design

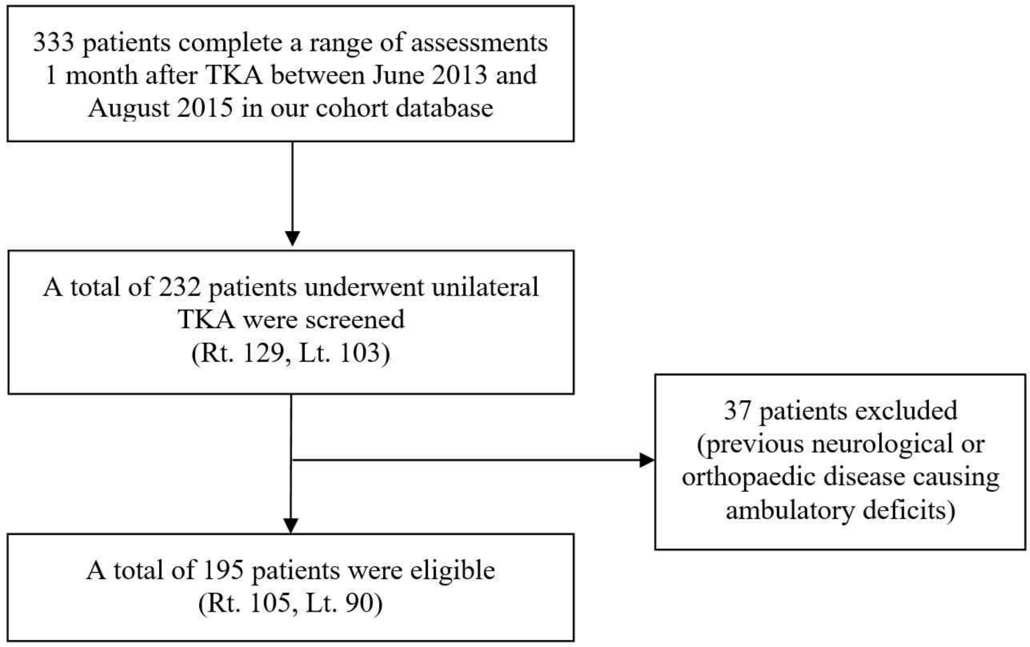
This was a cross-sectional study evaluating the relationship between objective performance-based physical function, self-reported physical function and quality of life, and gait function 1 month after unilateral TKA.

Participants

This retrospective study included one-hundred and ninety-five elderly people (32 males and 163 females; average age: 72.6 ± 6.1 years) diagnosed with end-stage primary OA of the knee and who underwent a unilateral primary TKA at the Department of Orthopedic Surgery in Jeju National University Hospital between June 2013 and August 2015. Approximately, two weeks after TKA, all patients were transferred to the rehabilitation department. The inclusion criteria consisted of the ability to walk independently with or without an ambulatory aid. We excluded patients who had previous neurological or orthopedic disease causing ambulatory deficits, such as orthopedic injury or previous joint surgery in lower extremities and unstable cardio-respiratory disease. And the patients who underwent a bilateral TKA were excluded. Of 232 screened patients, a total of 195 patients passed the inclusion and exclusion criteria, and were finally enrolled into the study (Fig 1). Of the excluded patients, 12 patients had a history of previous orthopedic injury and 10 patients underwent a bilateral TKA. The remaining 15 patients who had a history of neurological disease such as stroke and myelopathy were excluded.

Each participant received information about the study and gave written informed consent. The study protocol was approved by the Institutional Review Board of our hospital.

Figure 1. Flow diagram of patients selection process



Rehabilitation protocol

All patients underwent a rehabilitation program including a passive knee range of motion (ROM) exercise, progressive resistance strengthening exercise, gait training, aerobic exercise using an ergometer, functional training for transfers and stair climbing, and physical modalities such as cryotherapy and transcutaneous electrical nerve stimulation (TENS) for relief of knee pain and swelling. Progressive resistance strengthening was performed using concentric knee extensions, flexions, and hip abduction and adduction exercises using air resistance machines (HUR® machines, HUR Ltd., Kokkola, Finland) at 30% of their one-repetition maximum (1RM), for three sets of 15 repetitions, in 30 minute sessions. The 1RM was reassessed every week, and the training prescription was determined and progressed to a new resistance level until patients performed 60% of 1RM for three sets of ten repetitions. Gait training was performed using a lower-body positive pressure (LBPP) treadmill (AlterG® M/F320 Anti-Gravity Treadmill®, AlterG Inc., Fremont, CA, USA). All patients started at a workload of 50% bodyweight (BW) support and walked at a speed of 2.0 km/hr. When the patients could perform more repeats than initially set at a specific % BW and gait speed, the training was increased until 90% BW and a speed of 3.5 km/hr were reached. All rehabilitation programs were performed five times per week for a 2-week period, under the supervision of physical therapists. Post-operative knee pain was controlled by oral medication and did not change during the 2-week rehabilitation period. Two weeks after inpatient rehabilitation program, all patients were discharged to home and continued a home exercise program.

Outcome measures

All patients completed a range of assessments 1 month after surgery. Objective performance-based physical function tests included instrumental gait analysis for spatiotemporal variables, isometric knee extensor and flexor strength tests of the surgical and non-surgical knees, a 6 minute walk test (6MWT), a timed up-and-go (TUG) test, and a timed stair climbing test (SCT). Self-reported physical function was evaluated using WOMAC, and self-reported quality of life was evaluated using the EuroQol five dimension (EQ-5D) questionnaire. A VAS of postoperative knee pain was also recorded.

Assessment of objective performance-based physical function

Gait analysis

The spatiotemporal variables of gait were measured using a validated 24 wireless inertial sensing device (G-Walk®, BTS Bioengineering S.p.A., Milan, Italy) (Fig 2). The semi-elastic back-belt device is worn on the patient's waist and measures the 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 (Bugane F et al., 2012).

Figure 2. The figure shows spatiotemporal gait analysis using a validated 24 wireless inertial sensing device (G-Walk®, BTS Bioengineering S.p.A., Milan, Italy)

Measurement of the isometric strength of the knee extensors and flexors

The maximal isometric strength of the bilateral knee extensors and flexors was measured using an isokinetic dynamometer (HUMAC®/Norm™, CSMI, Stoughton, MA, USA) (Fig 3). All patients relaxed their muscle with light stretching before the test. Participants were seated on a specially designed chair and attained a hip angle of approximately 85° (Maffiuletti NA et al., 2007). The distal shin pad of the dynamometer was attached 2–3 cm proximal to the lateral malleolus using a strap. Additional straps were applied across the chest, pelvis, and mid-thigh to minimize inappropriate trunk movements during thigh muscle contractions. The alignment between the dynamometer rotational axis and the knee joint rotation axis (lateral femoral epicondyle) was adjusted at the beginning of each trial. The gravity effect torque was recorded for each subject and used to correct the torque measurements during all tests. Patients were asked to grasp the sidebars during the testing procedure. The length of the moment arm measured from the lateral femoral epicondyle to the center of the force transducer at the shin was kept constant. Data were obtained from digitized signals. After a structured warm-up with the knee joint fixed at 60° of flexion for maximal isometric force generation (Thorstenssoon A et al., 1976), patients were asked to perform maximal voluntary contractions until the torque did not increase by more than 5% during three successive attempts. Knee flexion and extension were performed as discrete movements in a single direction (i.e., non-reciprocal). Each contraction lasted 4–5 seconds, with the contractions being separated by 2 minutes of rest. During each attempt, the physical therapist loudly encouraged the patients to achieve their maximal performance. After a 5-minute rest, the same procedure was performed with the alternate lower limb. The variables analyzed included extensor and flexor peak torque (PT) of the surgical and non-surgical knees, and the difference in strength of the extensors and flexors between the surgical and non-surgical knees expressed as a percentage of non-surgical knee performance.

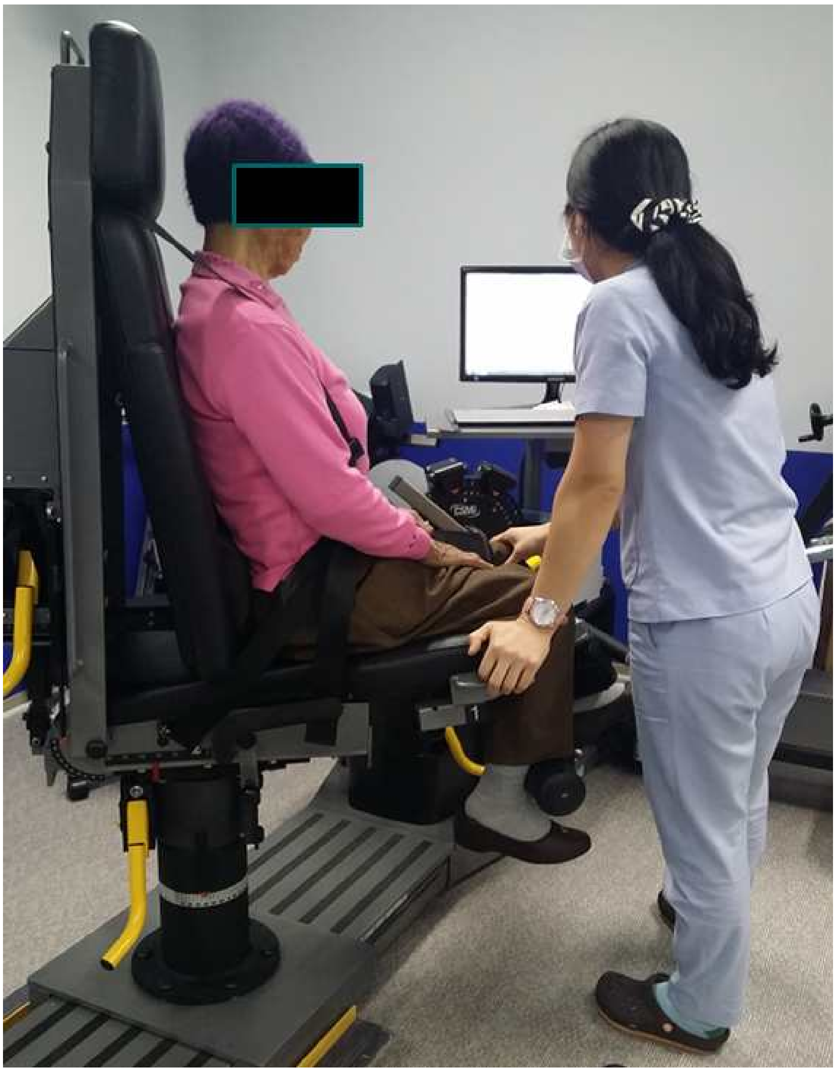


Figure 3. The figure shows isometric muscular strength of knee extensor and flexors using an isokinetic dynamometer (HUMAC®/Norm™, CSMI, Stoughton, MA, USA)

Six minute walk test

The 6MWT is a performance-based measure of exercise tolerance and functional walking capacity in adults. Patients were instructed to walk as far as possible for 6 minutes, through a 50m hallway marked with lines. They were permitted to use walking aids during the test if they were unable to walk independently. The 6MWT has high reliability in patients who have undergone primary TKA (Jakobsen TL et al., 2013).

Timed up-and-go test

The TUG test is an evaluation of dynamic balance performance. Each patient sat with their back against a chair (seat height, 44 cm; depth, 45 cm; width, 49 cm; arm rest height, 64 cm) placed at the end of a marked 3 m distance. Patients were instructed to stand up on the word “go”, walk at a comfortable speed past the 3 m mark, turn around, walk back, and sit down again in the chair without physical assistance, while being timed. The TUG tool has acceptable concurrent validity for measuring dynamic balance (Podsiadlo D et al., 1991).

Stair-climbing test

The SCT was measured as the time required to ascend and descend a flight of stairs (12 steps, each 17 cm high and 25 cm wide). Patients were asked to ascend or descend the stairs as fast as possible on the word “go”. Each trial was performed with a 5 minute rest interval and the best score was recorded (Almeida et al., 2010). All patients completed 3 trials and the fastest time was recorded.

Assessment of self-reported physical function, quality of life and pain

Western Ontario McMaster Universities Osteoarthritis Index

The multidimensional WOMAC questionnaire asks questions about pain, stiffness, and physical function, and has been used previously to measure self-reported disability in patients with knee OA. The questionnaire includes five pain variables, two stiffness variables, and 17 physical function variables. Each of these variables is scored using the Likert scale (0, none; 1, slight; 2, moderate; 3, very; and 4, extremely), as recommended by the Outcome Measures in Rheumatology Clinical Trials. The Likert scale is used to determine the degree of pain, stiffness, and difficulty experienced in performing each of 17 activities in the preceding 48 hours. Higher scores indicate greater levels of pain, stiffness, and difficulty (Bellamy N et al., 1988). The scores for pain, stiffness, and physical function variables are added to yield the WOMAC pain (range, 0–20), WOMAC-Stiffness (range, 0–8), and WOMAC-Function (range, 0–68) sub-scores.

EuroQol five dimensions questionnaire

The EQ-5D questionnaire is used to evaluate self-reported quality of life, and the EQ-5D Index is widely used to measure general health status. The instrument consists of a questionnaire with five dimensions: mobility, self-care, usual activities, pain/discomfort, and anxiety/depression. Each dimension is represented by one question with three severity levels (no problems, some or moderate problems, and extreme problems). Scores were transformed using utility weights derived from the general Korean population and ranged from −1 to 1. Higher scores indicate better overall health status. The formula for the EQ-5D Index has been presented by Kim et al. (Kim MH et al., 2005).

Visual analogue scale

Patients were asked to evaluate their level of knee pain using a VAS 1 month after TKA. The scale consisted of a 10 cm-long horizontal line ranging from completely satisfied to totally unsatisfied. Facial expressions were put above the line to express satisfaction visually. The satisfaction VAS system ranged from 0 (worst, totally unsatisfied) to 10 (best, completely satisfied) points (Carlsson AM et al., 1983). All patients received this scale and were asked to mark the line at a point that matched their satisfaction.

Statistical Analysis

All statistical analyses were performed using SPSS for Windows version 20.0 (SPSS V 20.0K, SPSS Inc., Chicago, Illinois, USA).

All variables were subjected to descriptive statistics. Pearson's correlation analysis was used to assess the relationships between gait speed and endurance, objective performance-based physical function values, and self-reported physical function, quality of life scores and VAS. Multivariate regression analysis using a backward selection linear regression model was employed to determine which objective performance-based physical function variables best explained gait speed and endurance 1 month after TKA. A p-value < 0.05 was considered significant.

III. RESULTS

Baseline demographic and disease-related characteristics are presented in Table 1.

There were 163 females and 32 men, with the average age being 72.6 ± 6.1 years. The average body mass index (BMI) was 26.0 ± 3.1 kg/m^2. Of the 195 patients, 155 (79.5%) had Kellgren-Lawrence (K-L) grade IV and 100 (51.3%) had osteoporosis. There were no infections, wound problems, nerve injuries, or any other postoperative complications.

Table 1. Demographic and Disease-related Characteristics of the Subjects (N=195)

Variables	Values
Age (years)	72.6 ± 6.1
Sex, males/females	32 (16.4) / 163 (83.6)
Height (cm)	152.2 ± 15.1
Weight (kg)	62.8 ± 13.6
BMI (kg/m^2)	26.0 ± 3.1
Postoperative duration (days)	16.0 ± 1.9
K-L grades	
Grade 3	40 (20.5)
Grade 4	155 (79.5)
Lesion side	
Right	105 (53.8)
Left	90 (46.2)
Comorbidities	
Cardiovascular disease	8 (4.1)
Diabetes mellitus	46 (23.6)
Hypertension	122 (62.6)
Spine disease	34(17.4)
Osteoporosis	100(51.3)

Values represent mean ± standard deviation or number (%) of cases

Abbreviations: BMI, body mass index; K-L, Kellgren-Lawrence

Postoperative objective performance-based physical function, self-reported physical function, quality of life and pain

The average postoperative objective performance-based physical function test, self-reported physical function, quality of life and pain scores of the patients are presented in Table 2.

Gait analysis showed that the average gait speed, cadence, stride length, and gait cycle duration were 1.0 ± 0.2 m/sec, 109.2 ± 13.7 steps/min, 105.2 ± 17.1 cm, and 1.2 ± 0.7 sec, respectively. In terms of isometric knee muscle strength, the average PT extensor values of the surgical and non-surgical knees were 48.9 ± 20.3 and 99.4 ± 36.6 $N \cdot m \cdot kg^{-1}$BW %, respectively, while the average PT flexor values of the surgical and non-surgical knees were 51.2 ± 16.0 and 60.2 ± 18.5 $N \cdot m \cdot kg^{-1}$BW % respectively. The average 6MWD, TUG, SCT-ascent, and descent values were 320.0 ± 75.7 m, 16.7 ± 6.1 sec, 16.5 ± 6.3 sec, and 18.0 ± 6.8 sec, respectively. The average knee flexion ROM and extension ROM were 110.8 ± 12.0° and -5.8 ± 5.5°. The average VAS were 3.5 ± 1.4 and WOMAC pain, stiffness, function, and EQ-5D were 4.3 ± 2.2, 2.6 ± 1.5, 18.5 ± 7.0, and 0.8 ± 0.1 respectively.

Table 2. The Evaluation of Gait Function, Objective Performance-based Physical Function, Self-reported Physical Function, Quality of Life and Pain 1month after TKA

Variable	Values
Gait linear parameter	
Gait Speed (m/sec)	1.0 ± 0.2
Cadence (steps/min)	109.2 ± 13.7
Stride length (cm)	105.2 ± 17.1
Gait cycle duration (sec)	1.2 ± 0.7
Stance phase duration (% of gait cycle)	65.0 ± 1.9
Swing phase duration (% of gait cycle)	35.0 ± 1.9
Double support duration (% of gait cycle)	29.1 ± 4.9
Single support duration (% of gait cycle)	35.1 ± 3.4
Isometric strength test	
PT extensor of surgical knee ($N \cdot m \cdot kg^{-1}$BW %)	48.9 ± 20.3
PT flexor of surgical knee ($N \cdot m \cdot kg^{-1}$BW %)	51.2 ± 16.0
PT extensor of non-surgical knee ($N \cdot m \cdot kg^{-1}$BW %)	99.4 ± 36.6
PT flexor of non-surgical knee ($N \cdot m \cdot kg^{-1}$BW %)	60.2 ± 18.5
Deficit of extensor (%)	47.8 ± 20.2
Deficit of flexor (%)	16.7 ± 18.1
6MWT (m)	320.0 ± 75.7
TUG (sec)	16.7 ± 6.1
SCT (sec)	
Ascent	16.5 ± 6.3
Descent	18.0 ± 6.8
ROM (degrees)	
Knee flexion	110.8 ± 12.0
Knee extension	-5.8 ± 5.5
VAS	3.5 ± 1.4
WOMAC	
Pain	4.3 ± 2.2
Stiffness	2.6 ± 1.5

Function	18.5 ± 7.0
EQ-5D	0.8 ± 0.1

Values represent mean ± standard deviation

Abbreviations: PT, peak torque; BW, body weight; 6MWT, 6 minute walk test; TUG, timed up and go; SCT, timed stair climbing test; ROM, range of motion; VAS, visual analog scale; WOMAC, Western Ontario McMaster Universities Osteoarthritis Index; EQ-5D, EuroQol five dimensions

Correlation among gait speed, objective performance-based physical function, self-reported physical function, quality of life and pain

In the bivariate analyses, gait speed showed a significant positive correlation with the postoperative PT of the extensor of the surgical knee (r = 0.35, p < 0.001), postoperative PT of the extensor of the non-surgical knee (r = 0.43, p < 0.001), postoperative PT of the flexor of the surgical knee (r = 0.22, p < 0.001), postoperative PT of the flexor of the non-surgical knee (r = 0.21, p = 0.003), 6MWT (r = 0.48, p < 0.001), cadence (r = 0.40, p < 0.001), and stride length (r = 0.58, p < 0.001), while it negatively correlated with TUG (r = −0.44, p = <0.001), SCT-ascent (r = −0.50, p < 0.001), SCT-descent (r = −0.52, p < 0.001), VAS (r = −0.23, p = 0.001), WOMAC pain (r = −0.27, p < 0.001), stiffness (r = −0.46, p < 0.001), and function score (r = −0.34, p < 0.001), as shown in Table 3 & Fig. 4(A) - (N).

Table 3. Correlation among Gait Speed, Objective Performance-based Physical Function, Self-reported Physical Function, Quality of Life and Pain 1month after TKA

Variable	Correlation coefficients (*r*) Gait speed
Gait linear parameter	
Cadence (steps/min)	0.40†
Stride length (cm)	0.58†
Gait cycle duration (sec)	-0.07
Stance phase duration (% of gait cycle)	-0.08
Swing phase duration (% of gait cycle)	0.08
Double support duration (% of gait cycle)	0.10
Single support duration (% of gait cycle)	-0.05
Isometric strength test	
PT extensor of surgical knee ($N·m·kg^{-1}$BW %)	0.35†
PT flexor of surgical knee ($N·m·kg^{-1}$BW %)	0.22†
PT extensor of non-surgical knee ($N·m·kg^{-1}$BW %)	0.43†
PT flexor of non-surgical knee ($N·m·kg^{-1}$BW %)	0.21†
Deficit of extensor (%)	0.10
Deficit of flexor (%)	0.03
6MWT (m)	0.48†
TUG (sec)	-0.44†
SCT (sec)	
Ascent	-0.50†
Descent	-0.52†
ROM (degrees)	
Knee flexion	0.02
Knee extension	0.04
VAS	-0.23†

WOMAC	
Pain	$-0.27^{\dagger}$
Stiffness	$-0.46^{\dagger}$
Function	$-0.34^{\dagger}$
EQ5D	0.14

Values represent correlation coefficients (r)

*p<0.05, †p<0.01

Abbreviations: PT, peak torque; BW, body weight; 6MWT, 6 minute walk test; TUG, timed up and go; SCT, timed stair climbing test; ROM, range of motion; VAS, visual analog scale; WOMAC, Western Ontario McMaster Universities Osteoarthritis Index; EQ-5D, EuroQol five dimensions

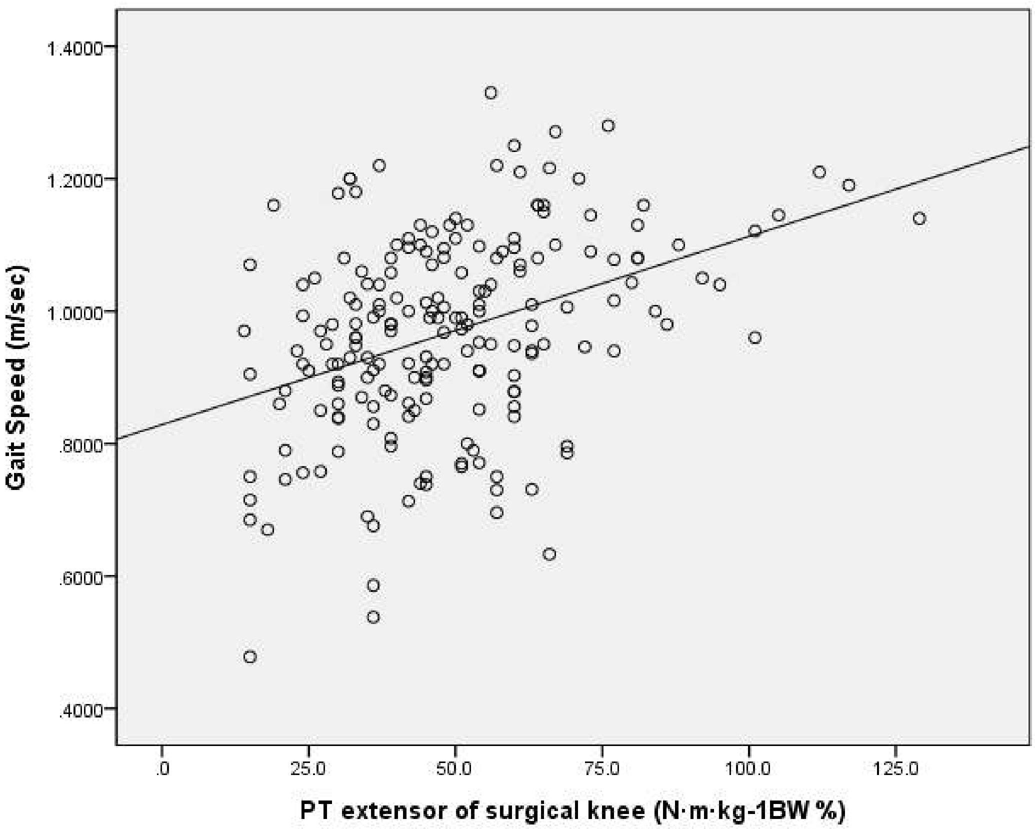


Figure 4(A). Correlation between gait speed and PT extensor of surgical knee

($r = 0.35$, $p < 0.001$)

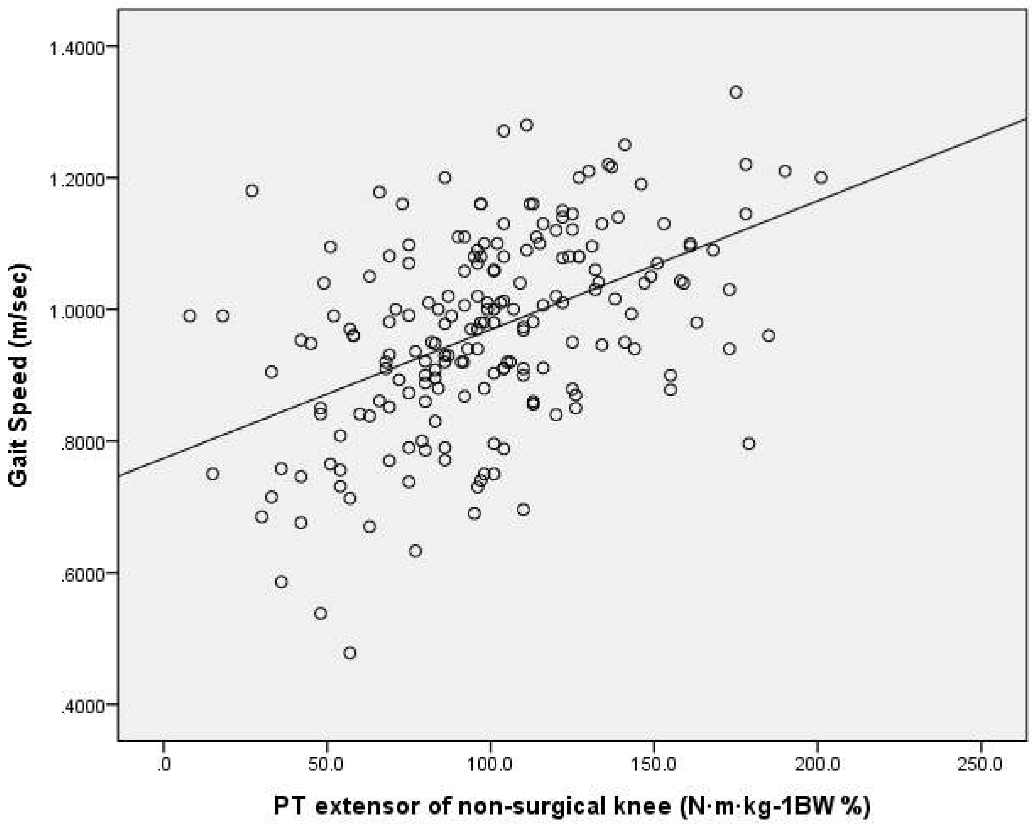


Figure 4(B). Correlation between gait speed and PT extensor of non-surgical knee

($r = 0.43$, $p < 0.001$)

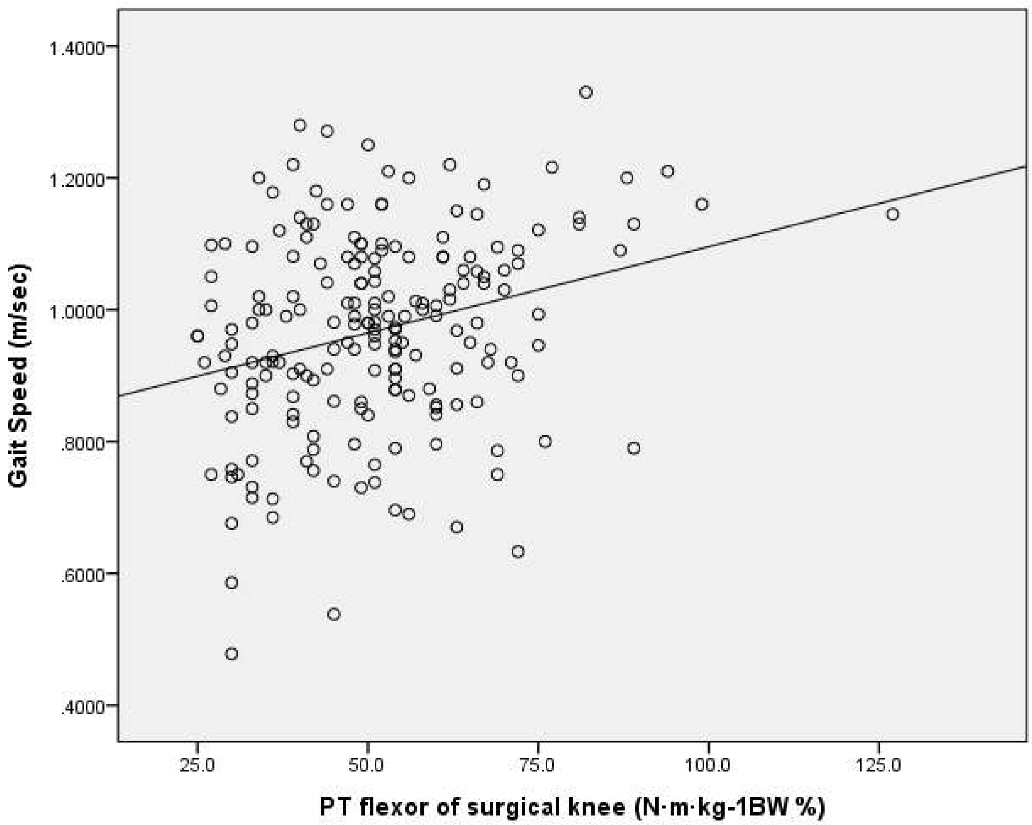


Figure 4(C). Correlation between gait speed and PT flexor of surgical knee

($r = 0.22$, $p < 0.001$)

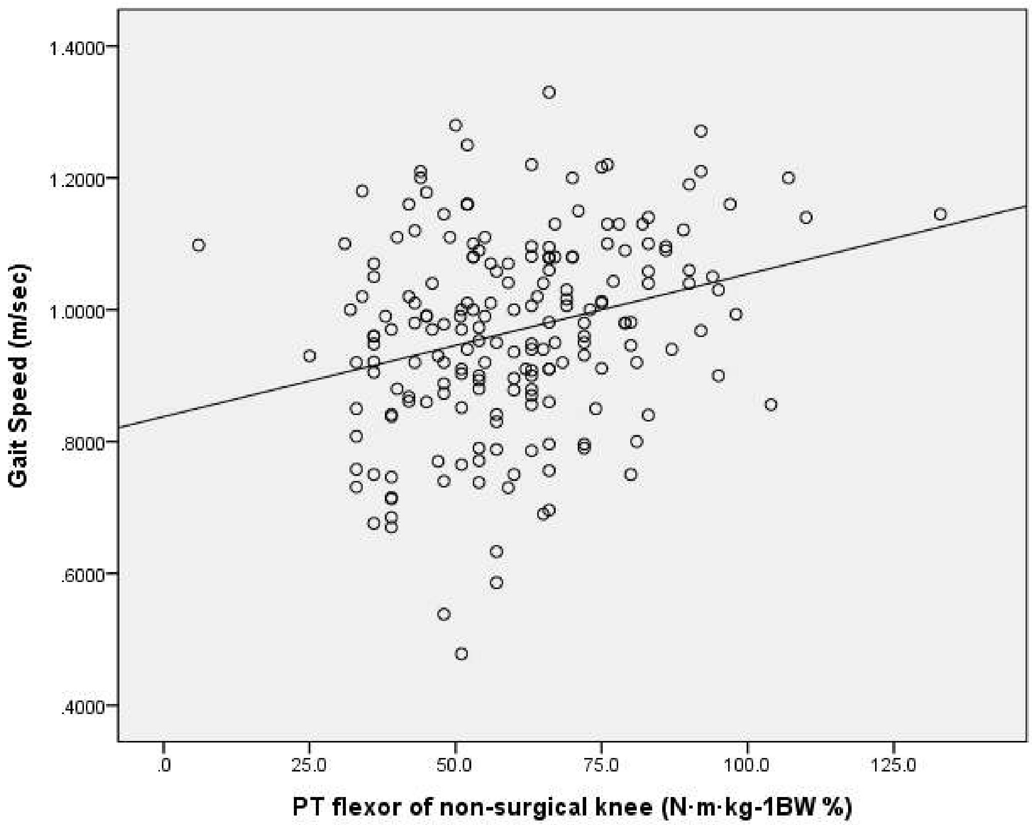


Figure 4(D). Correlation between gait speed and PT flexor of non-surgical knee

($r = 0.21$, $p = 0.003$)

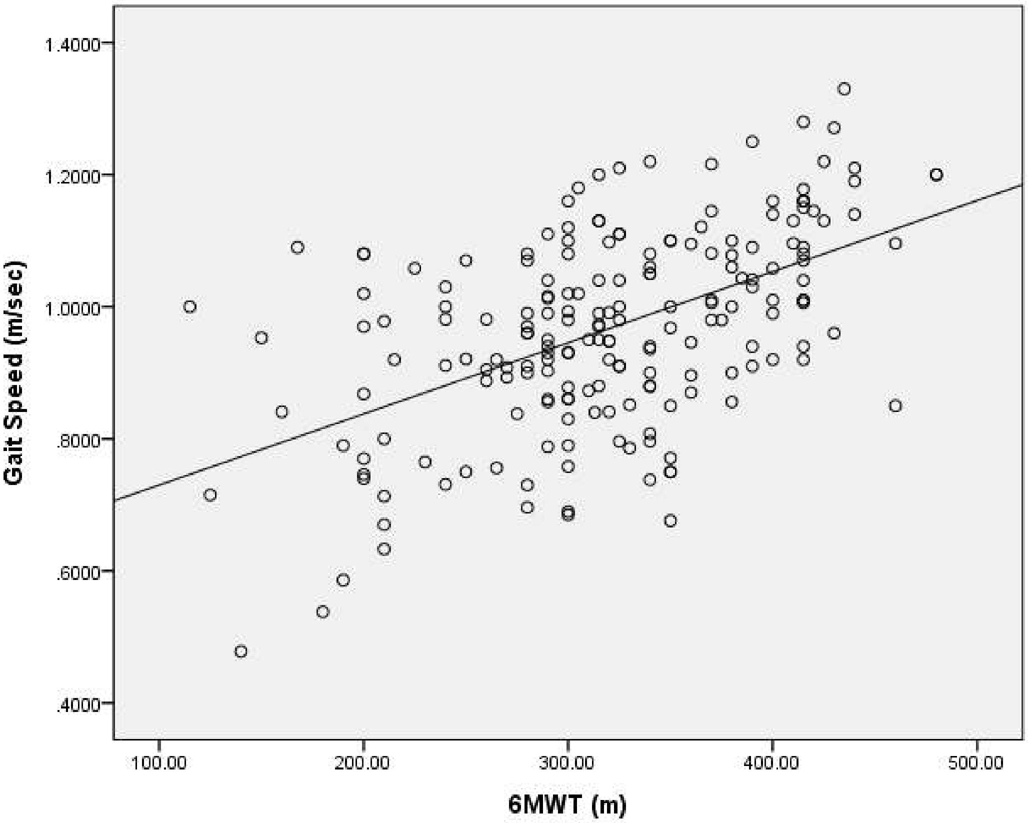


Figure 4(E). Correlation between gait speed and 6MWT (r = 0.48, p < 0.001)

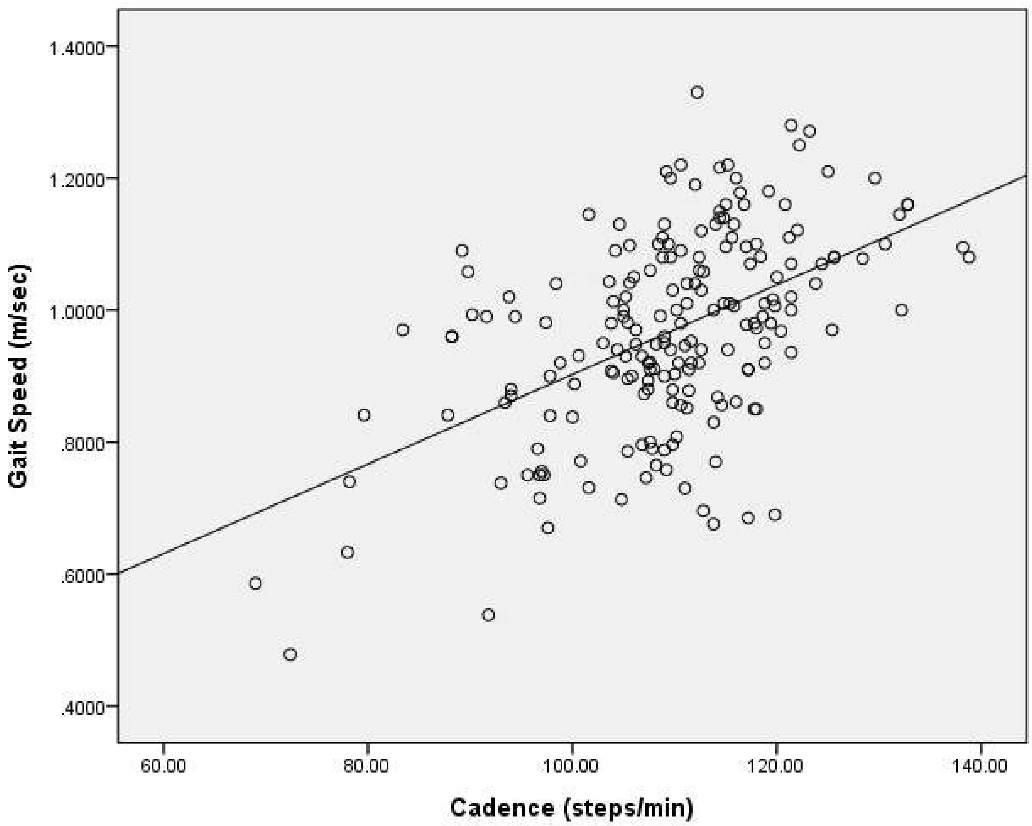


Figure 4(F). Correlation between gait speed and cadence ($r = 0.40$, $p < 0.001$)

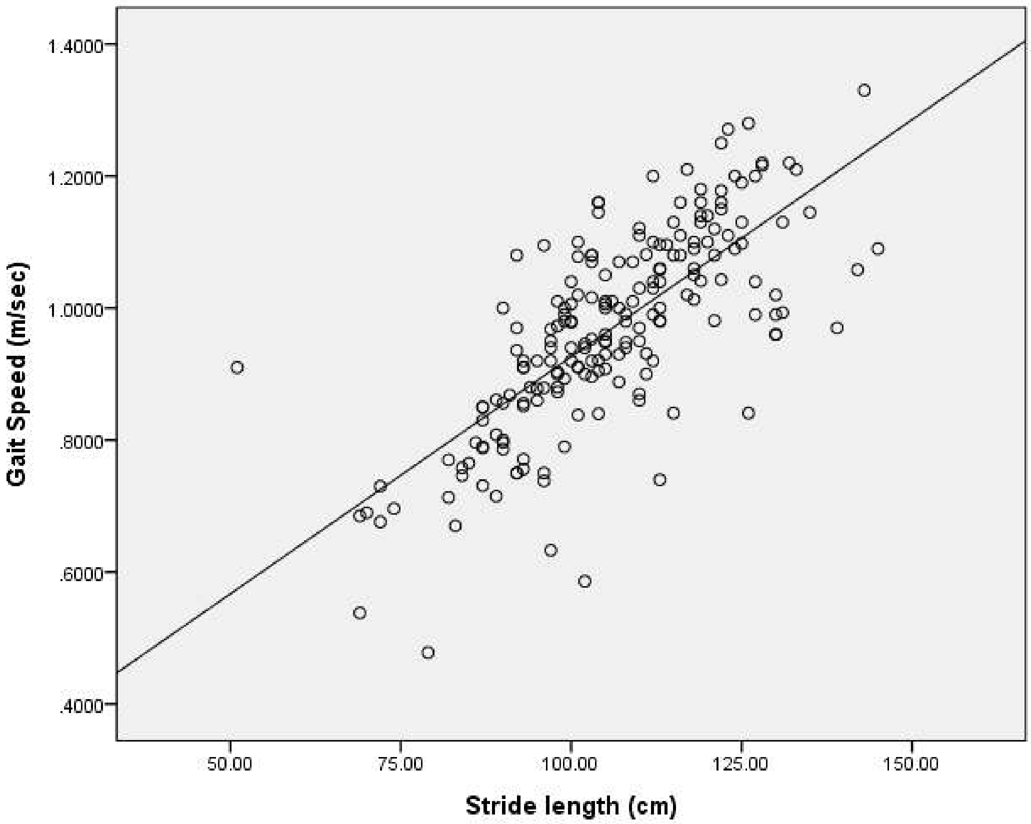


Figure 4(G). Correlation between gait speed and stride length (*r* = 0.58, *p* < 0.001)

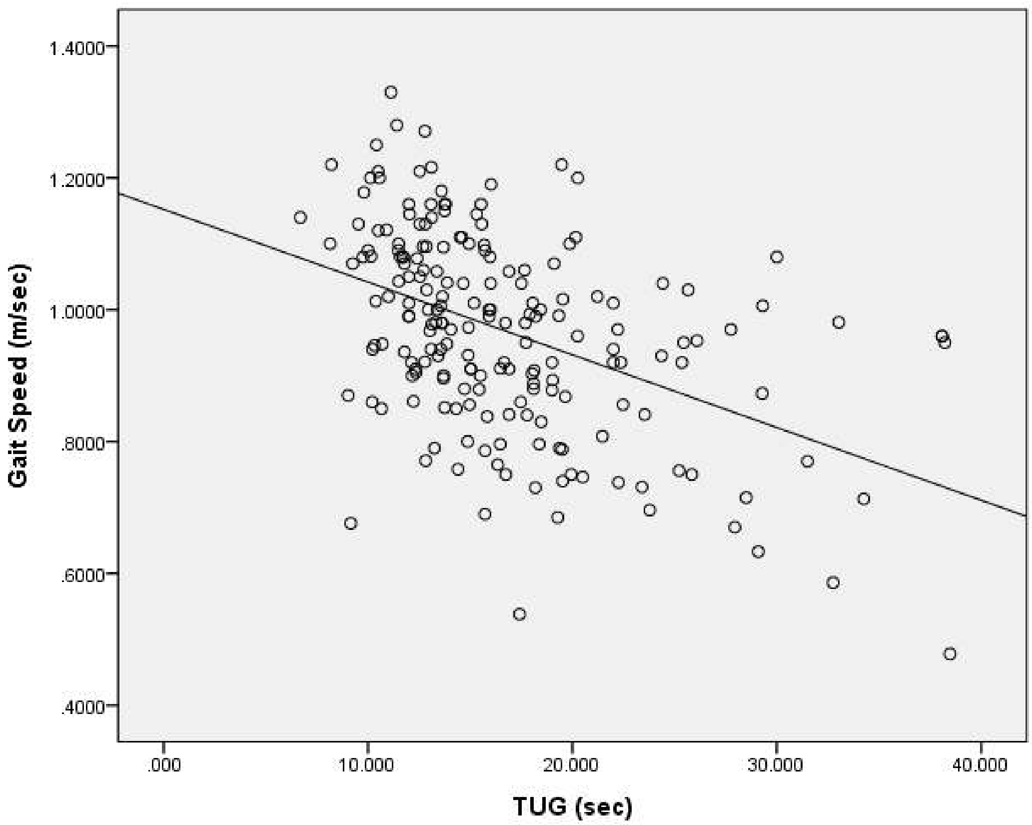


Figure 4(H). Correlation between gait speed and TUG (r = -0.44, p < 0.001)

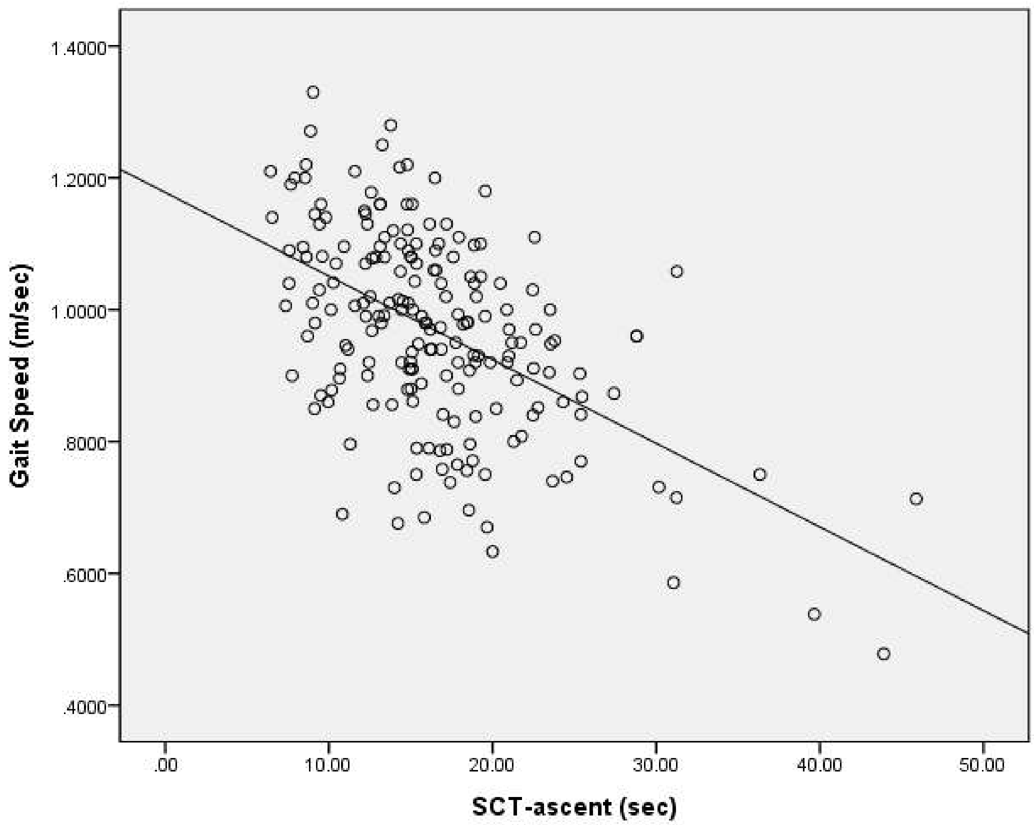


Figure 4(I). Correlation between gait speed and SCT-ascent (r = -0.50, p < 0.001)

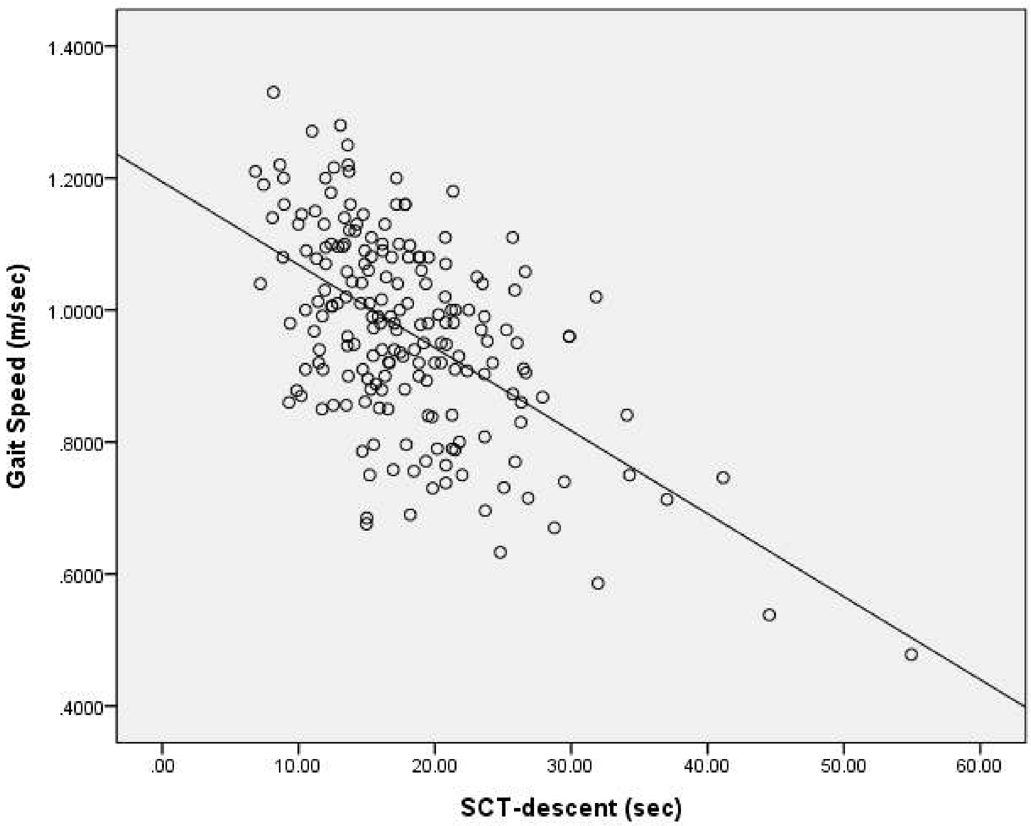


Figure 4(J). Correlation between gait speed and SCT-descent (*r* = -0.52, $p < 0.001$)

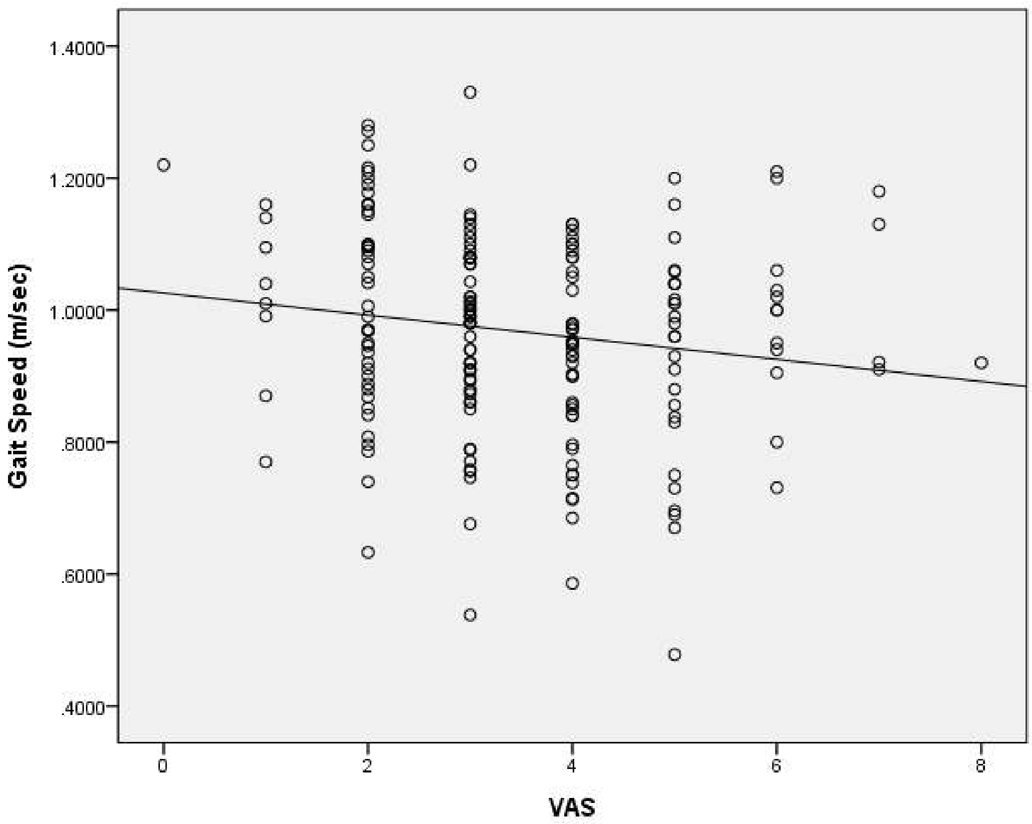


Figure 4(K). Correlation between gait speed and VAS (r = -0.23, p = 0.001)

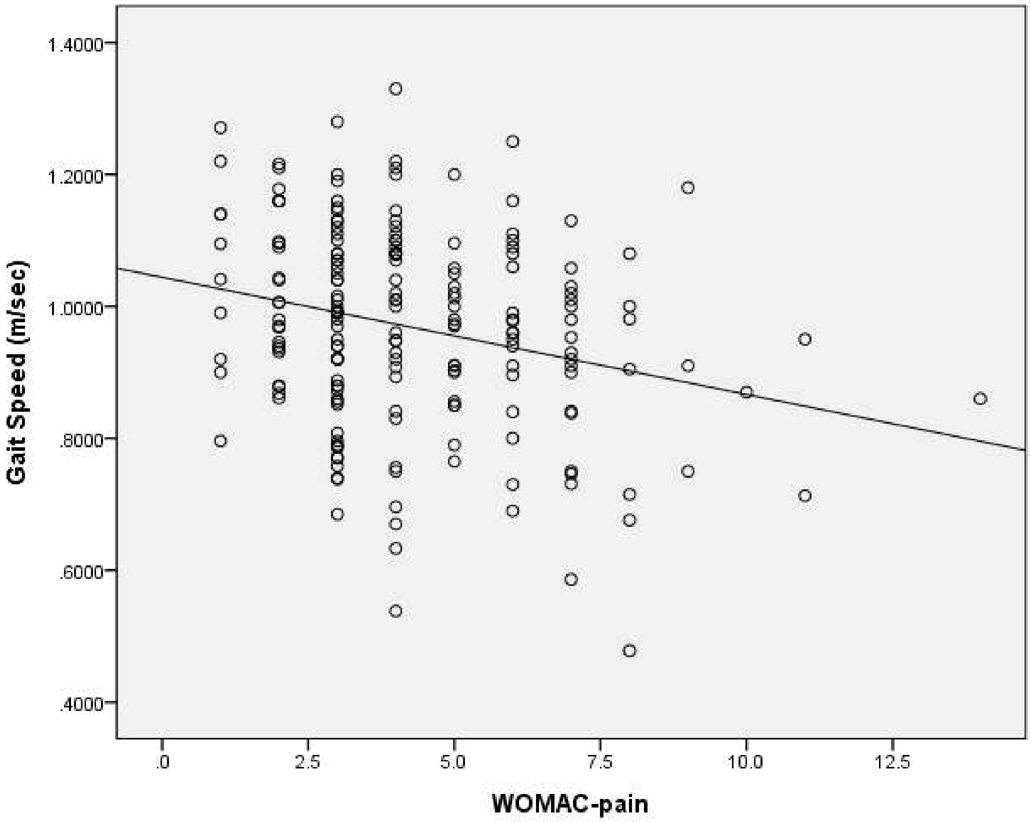


Figure 4(L). Correlation between gait speed and WOMAC-pain (r = -0.27, p < 0.001)

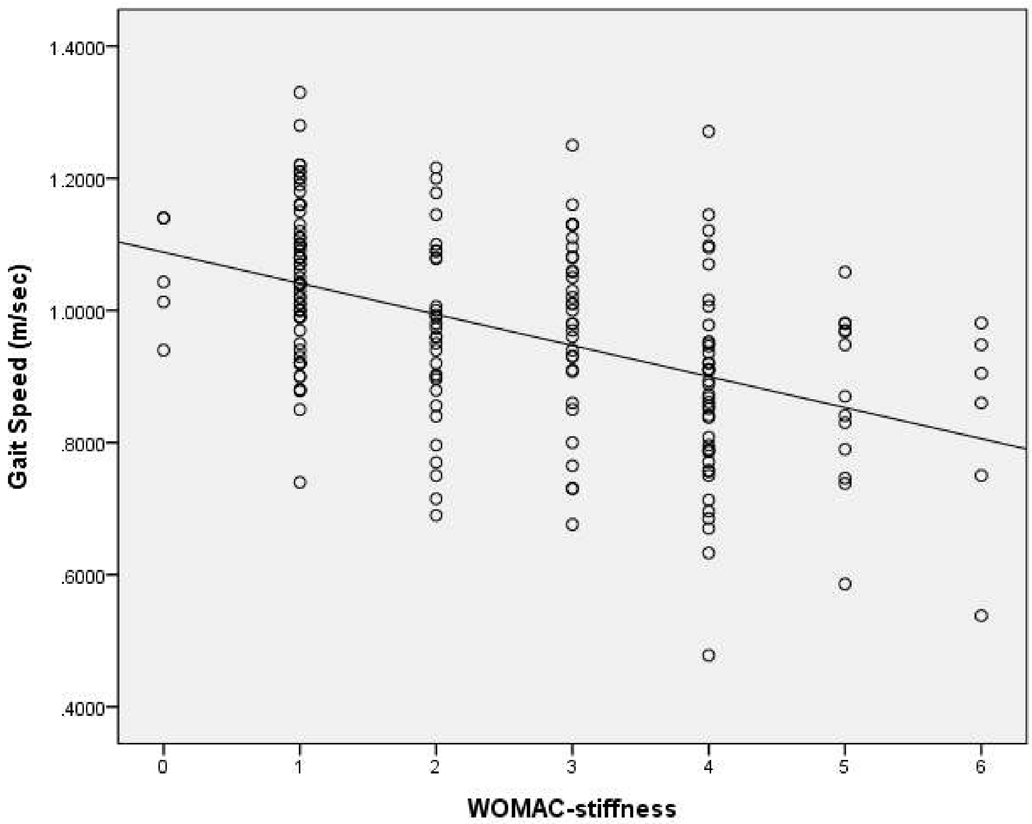


Figure 4(M). Correlation between gait speed and WOMAC-stiffness (r = -0.46, p < 0.001)

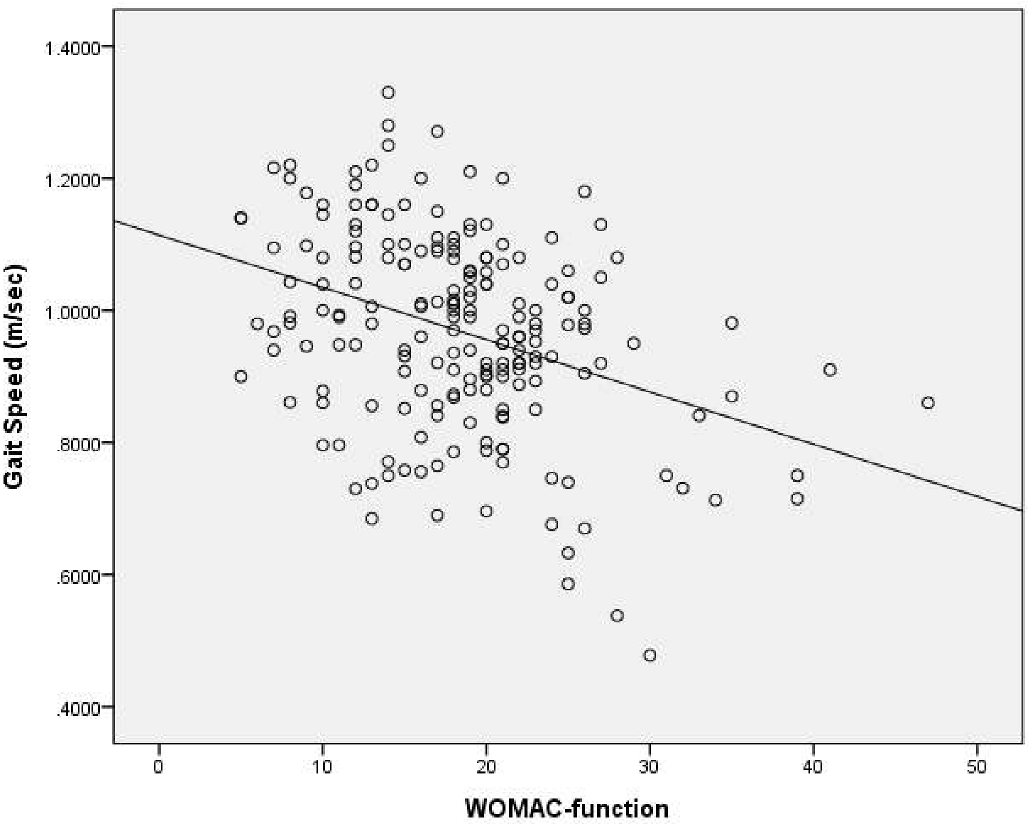


Figure 4(N). Correlation between gait speed and WOMAC-function (r = -0.34, p < 0.001)

After adjustment for demographics and anthropometric variables, the linear regression analysis showed that the postoperative PT extensor of the surgical knee ($\beta = 0.16$, $p = 0.04$), non-surgical knee ($\beta = 0.27$, $p < 0.001$), and VAS ($\beta = -0.15$, $p = 0.03$) were factors associated with the postoperative gait speed ($R^2 = 0.25$), as shown in Table 4.

Table 4. Factors correlated with Gait Speed by Multivariate Linear Regression Analysis

1month after TKA

Outcome/Independent Predictor	Standardized β	*p*-value	Adjusted R^2
Gait speed			
VAS	-0.15	0.03	0.25
PT extensor of surgical knee ($N \cdot m \cdot kg^{-1}$BW %)	0.16	0.04	
PT extensor of non-surgical knee ($N \cdot m \cdot kg^{-1}$BW %)	0.27	≤ 0.001	

Abbreviations: VAS, visual analog scale; PT, peak torque; BW, bodyweight

Correlation among gait endurance, objective performance-based physical function, self-reported physical function, quality of life and pain

In the bivariate analyses, the gait endurance showed significant positive correlations with the postoperative PT of the extensor of the surgical knee ($r = 0.36$, $p < 0.001$), postoperative PT of the extensor of the non-surgical knee ($r = 0.49$, $p < 0.001$), postoperative PT of the flexor of the surgical knee ($r = 0.25$, $p < 0.001$), postoperative PT of the flexor of the non-surgical knee ($r = 0.34$, $p < 0.001$), gait speed ($r = 0.48$, $p < 0.001$), cadence ($r = 0.34$, $p < 0.001$), stride length ($r = 0.23$, $p < 0.001$), and EQ-5D ($r = 0.33$, $p < 0.001$), while it showed significant negative correlations with TUG ($r = -0.46$, $p < 0.001$), SCT-ascent ($r = -0.63$, $p < 0.001$), SCT-descent ($r = -0.68$, $p < 0.001$), VAS ($r = -0.23$, $p = 0.001$), and WOMAC pain ($r = -0.29$, $p < 0.001$), stiffness ($r = -0.35$, $p < 0.001$), and function scores ($r = -0.43$, $p < 0.001$), as shown in Table 5 & Fig. 5(A) - (O).

Table 5. Correlation among Gait Endurance, Objective Performance-based Physical Function, Self-reported Physical Function, Quality of Life and Pain 1month after TKA

Variable	Correlation coefficients (r) Gait endurance (6MWT)
Gait parameter	
Gait Speed (m/sec)	0.48†
Cadence (steps/min)	0.34†
Stride length (cm)	0.23†
Gait cycle duration (sec)	-0.03
Stance phase duration (% of gait cycle)	-0.11
Swing phase duration (% of gait cycle)	0.11
Double support duration (% of gait cycle)	-0.02
Single support duration (% of gait cycle)	-0.01
Isometric strength test	
PT extensor of surgical knee ($N \cdot m \cdot kg^{-1}BW$ %)	0.36†
PT flexor of surgical knee ($N \cdot m \cdot kg^{-1}BW$ %)	0.25†
PT extensor of non-surgical knee ($N \cdot m \cdot kg^{-1}BW$ %)	0.49†
PT flexor of non-surgical knee ($N \cdot m \cdot kg^{-1}BW$ %)	0.34†
Deficit of extensor (%)	0.12
Deficit of flexor (%)	0.13
TUG (sec)	-0.46†
SCT (sec)	
Ascent (sec)	-0.63†
Descent (sec)	-0.68†
ROM (degrees)	
Knee flexion	0.08

Knee extension	0.04
VAS	-0.23†
WOMAC	
Pain	-0.29†
Stiffness	-0.35†
Function	-0.43†
EQ-5D	0.33†

Values represent correlation coefficients (r)

*p<0.05, †p<0.01

Abbreviations: PT, peak torque; BW, body weight; 6MWT, 6 minute walk test; TUG, timed up and go; SCT, timed stair climbing test; ROM, range of motion; VAS, visual analog scale; WOMAC, Western Ontario McMaster Universities Osteoarthritis Index; EQ-5D, EuroQol five dimensions

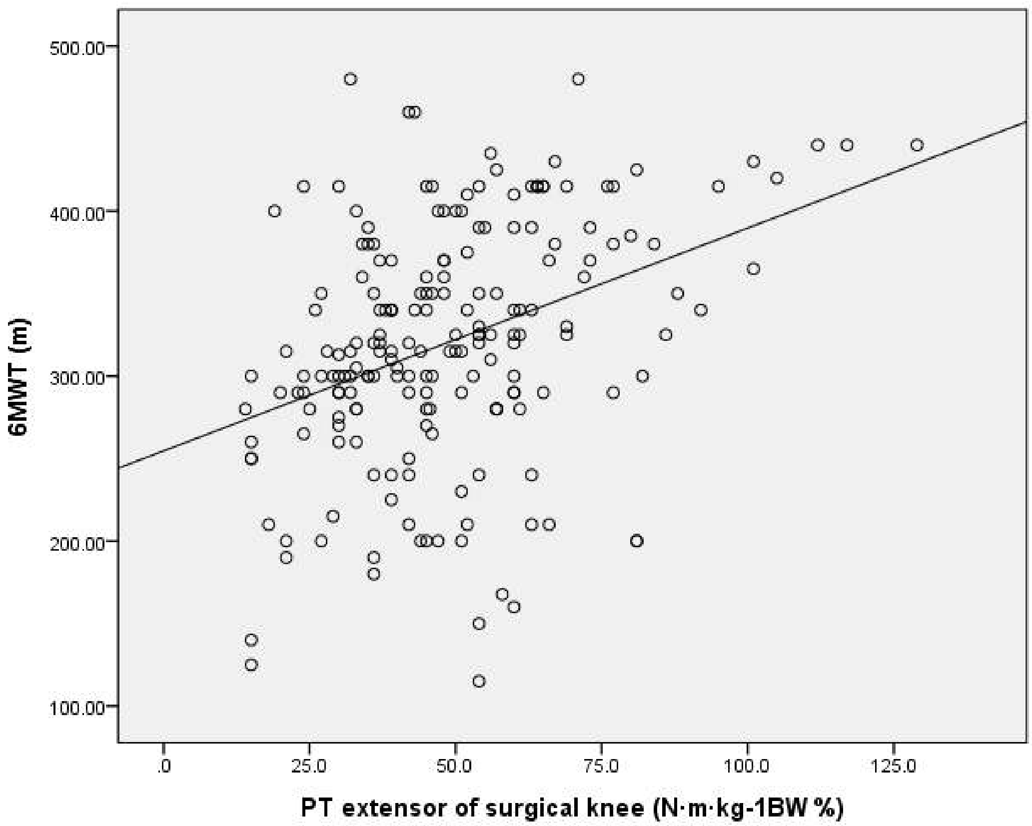


Figure 5(A). Correlation between gait endurance and PT extensor of surgical knee

($r = 0.36$, $p < 0.001$)

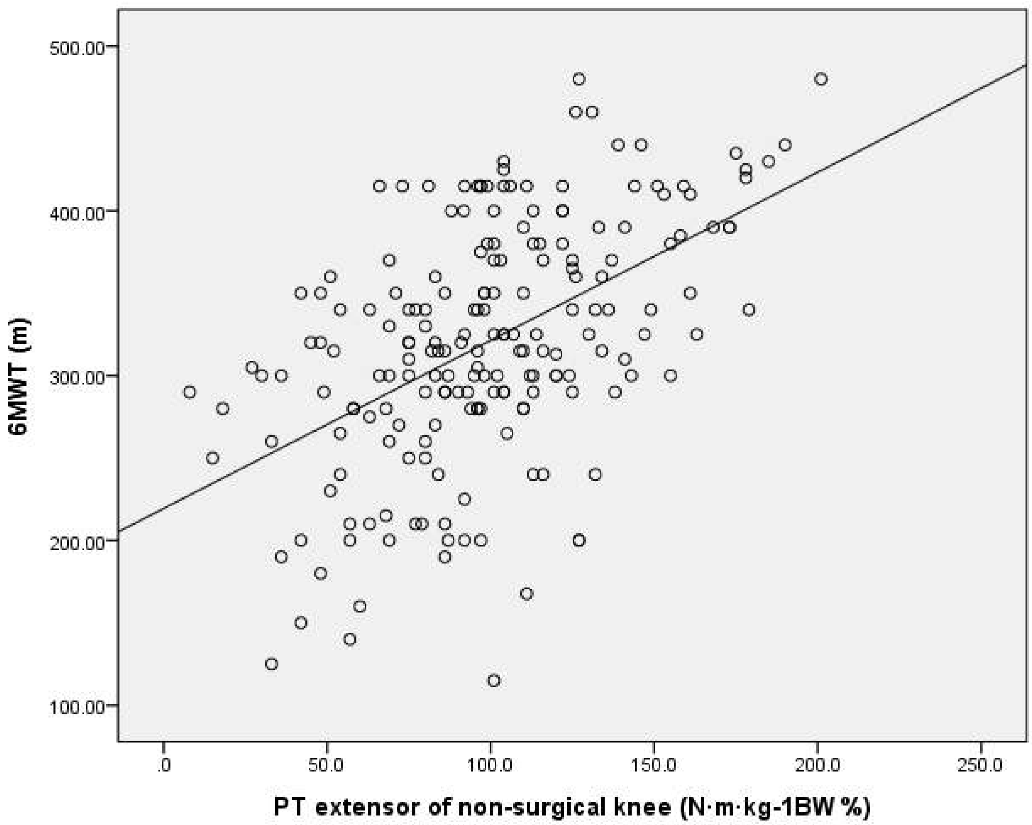


Figure 5(B). Correlation between gait endurance and PT extensor of non-surgical knee (r = 0.49, p < 0.001)

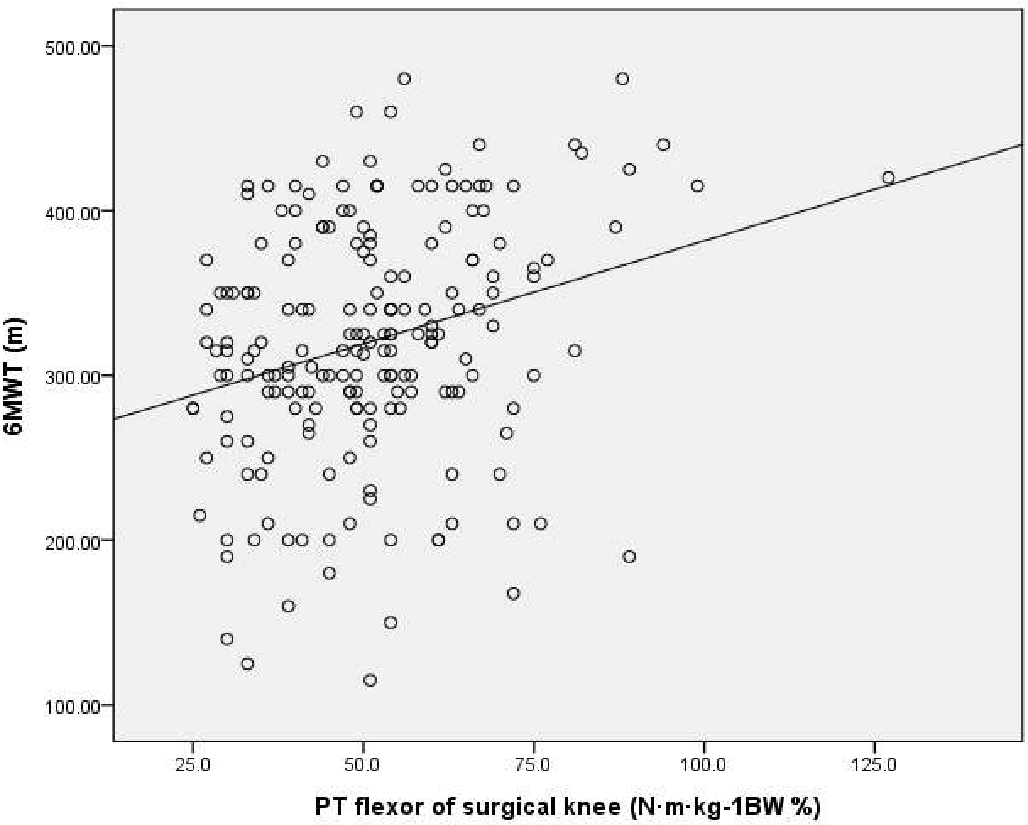


Figure 5(C). Correlation between gait endurance and PT flexor of surgical knee

($r = 0.25$, $p < 0.001$)

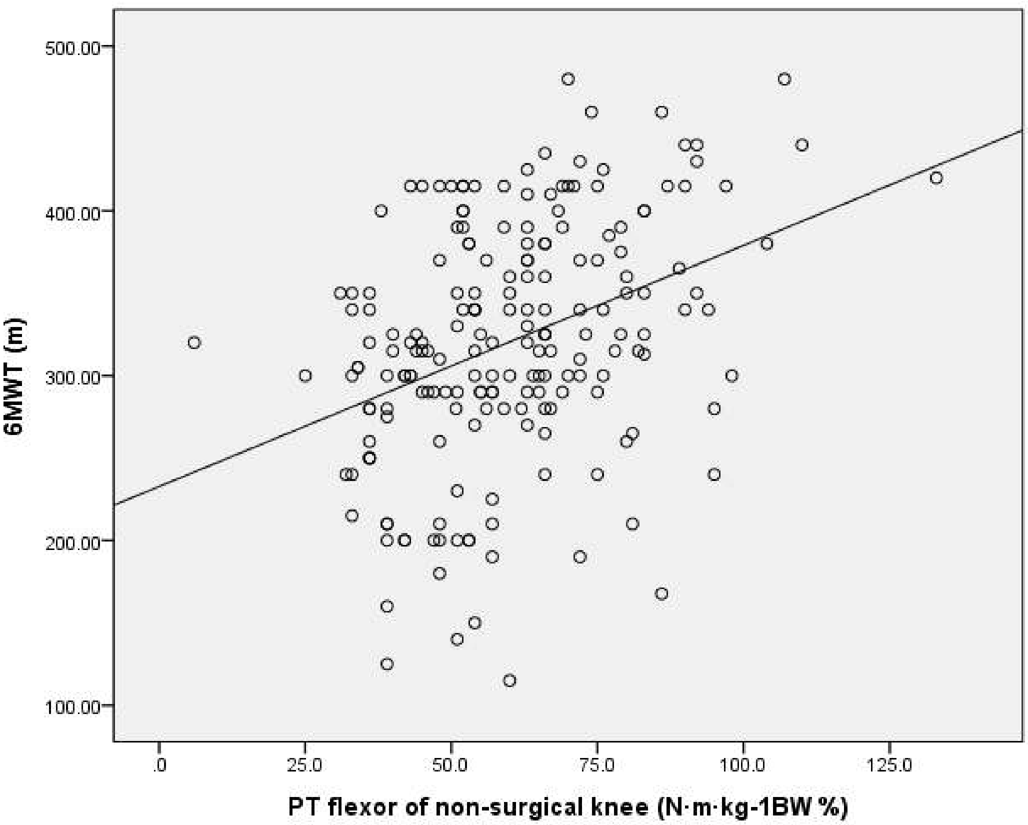


Figure 5(D). Correlation between gait endurance and PT flexor of non-surgical knee (r = 0.34, p < 0.001)

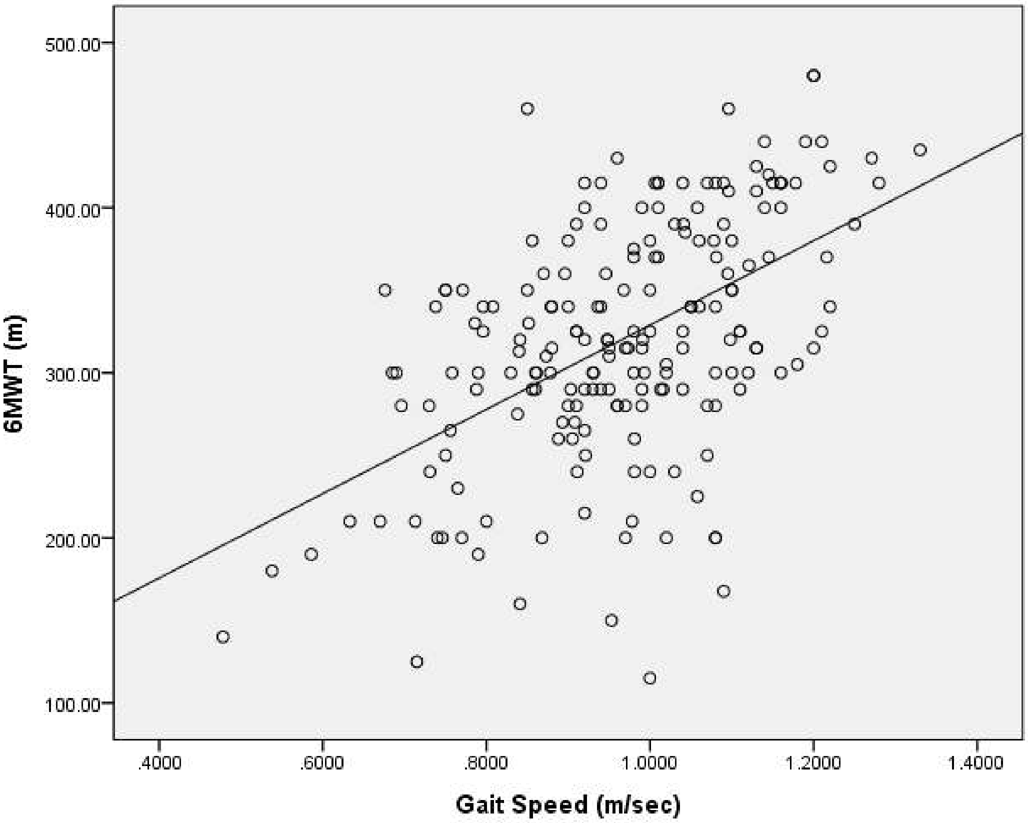


Figure 5(E). Correlation between gait endurance and gait speed (r = 0.48, p < 0.001)

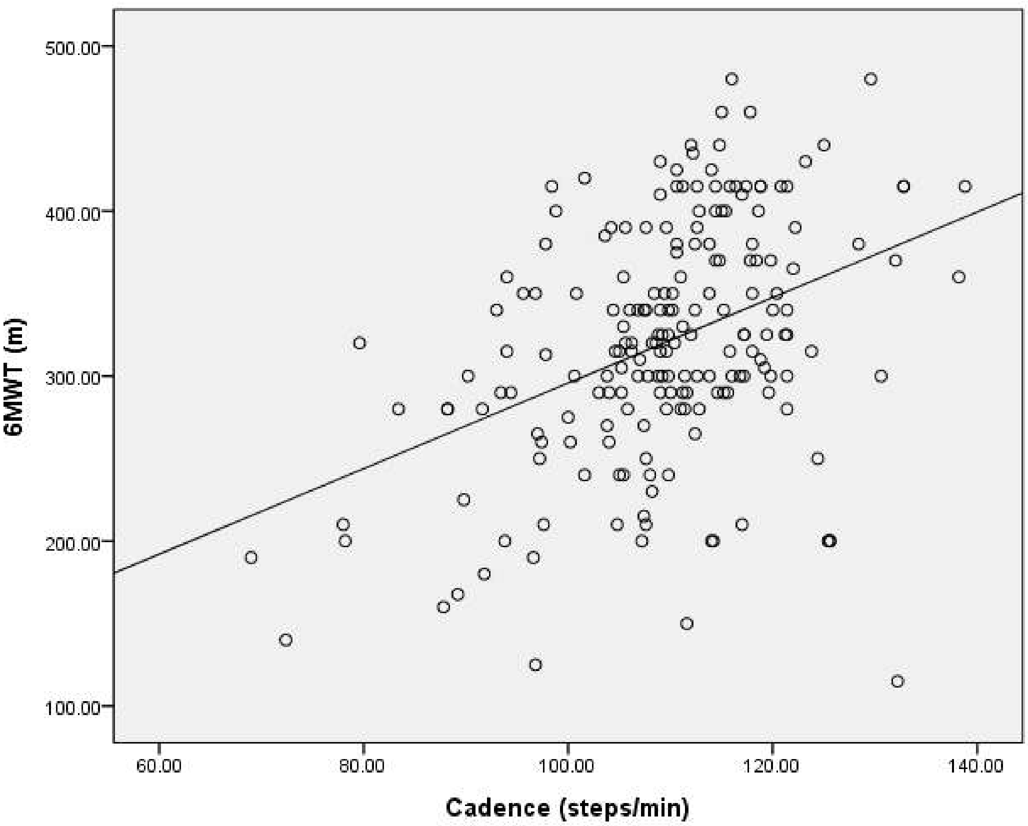


Figure 5(F). Correlation between gait endurance and cadence (r = 0.34, p < 0.001)

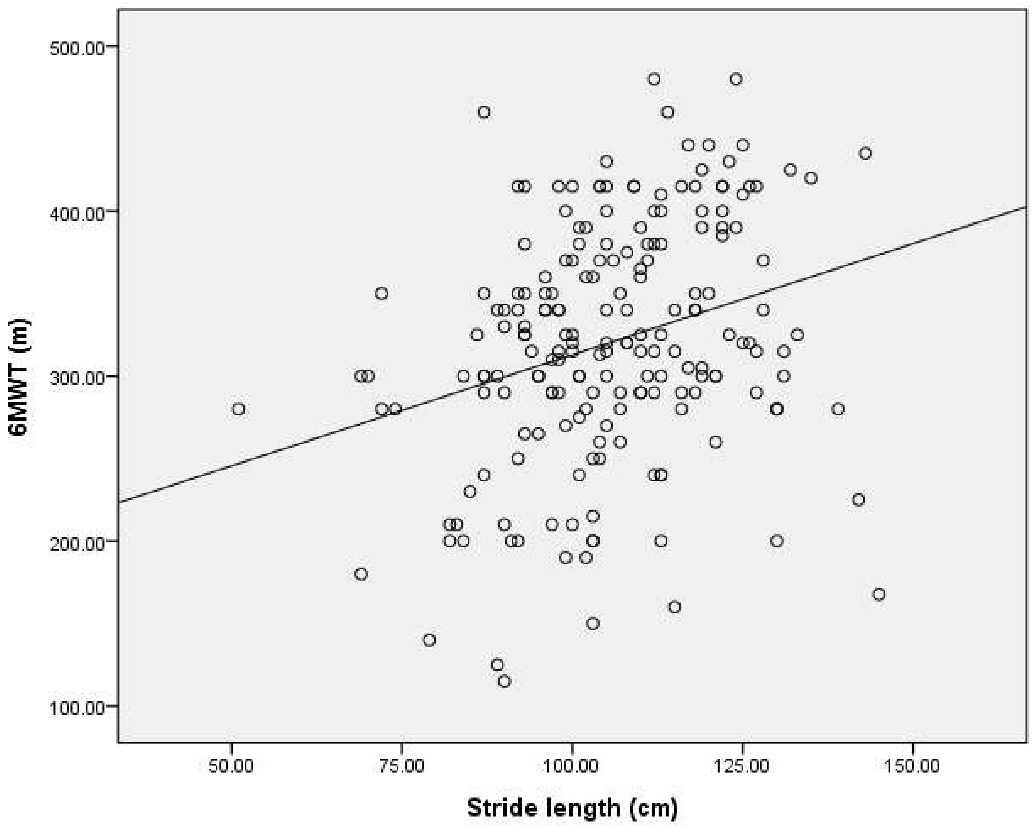


Figure 5(G). Correlation between gait endurance and stride length (r = 0.23, p < 0.001)

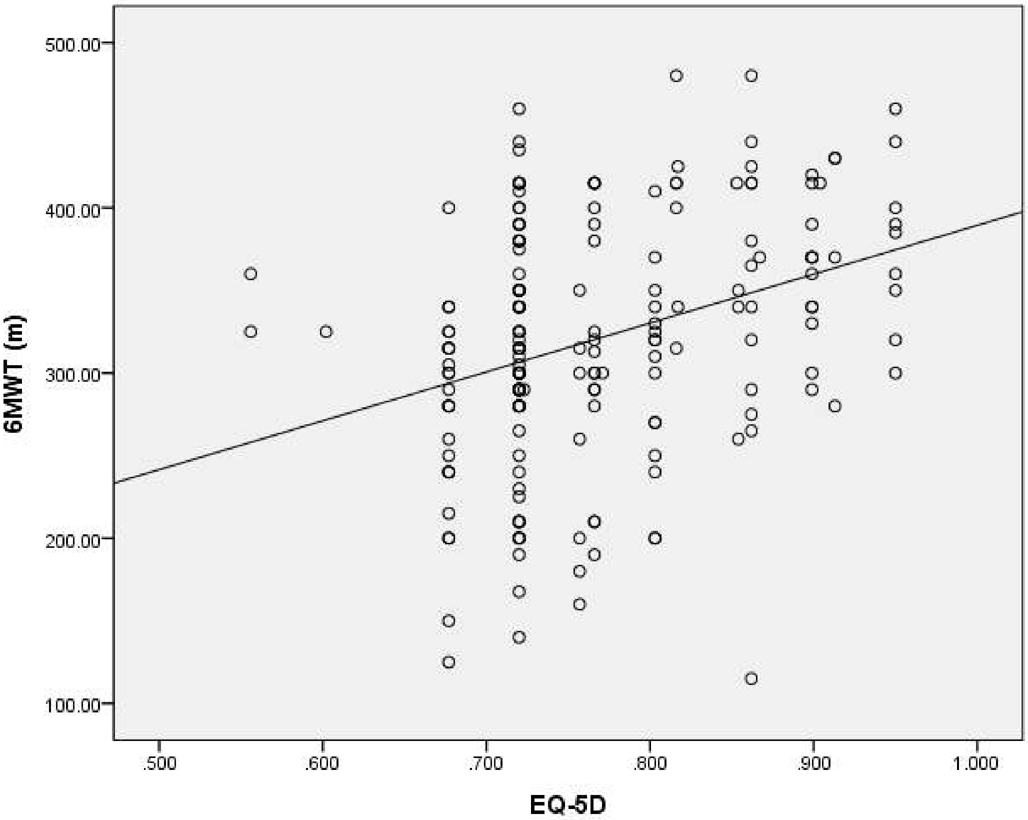


Figure 5(H). Correlation between gait endurance and EQ-5D (r = 0.33, p < 0.001)

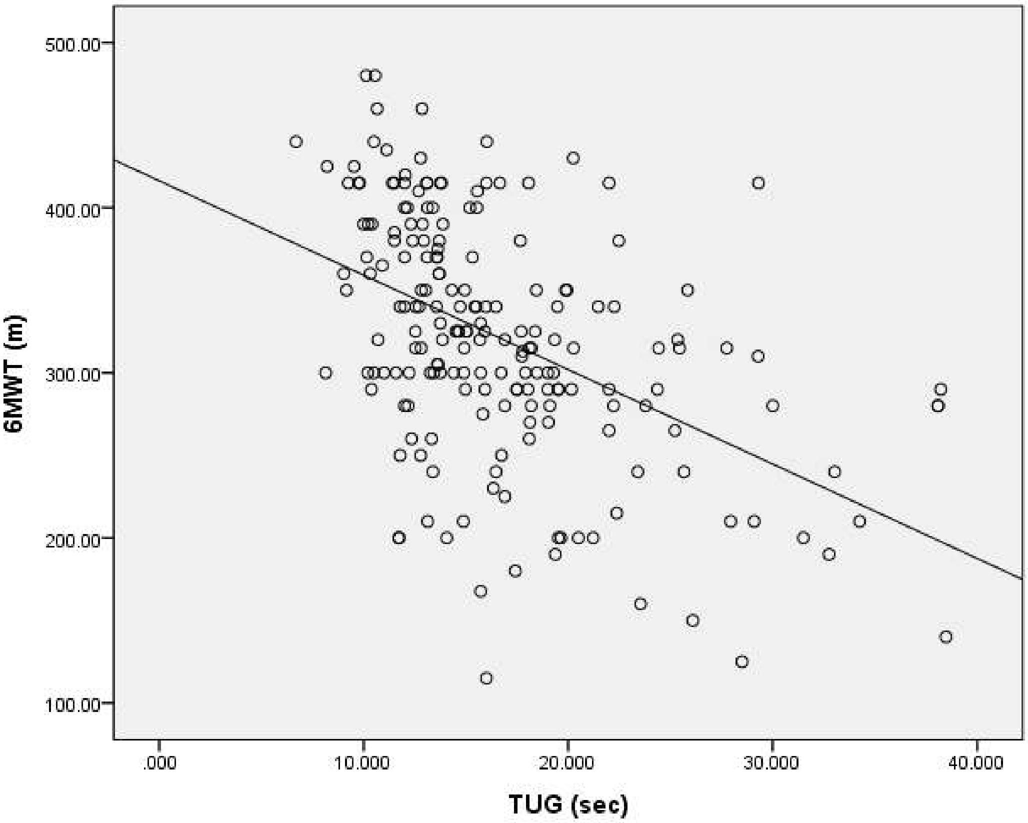


Figure 5(I). Correlation between gait endurance and TUG (r = -0.46, p < 0.001)

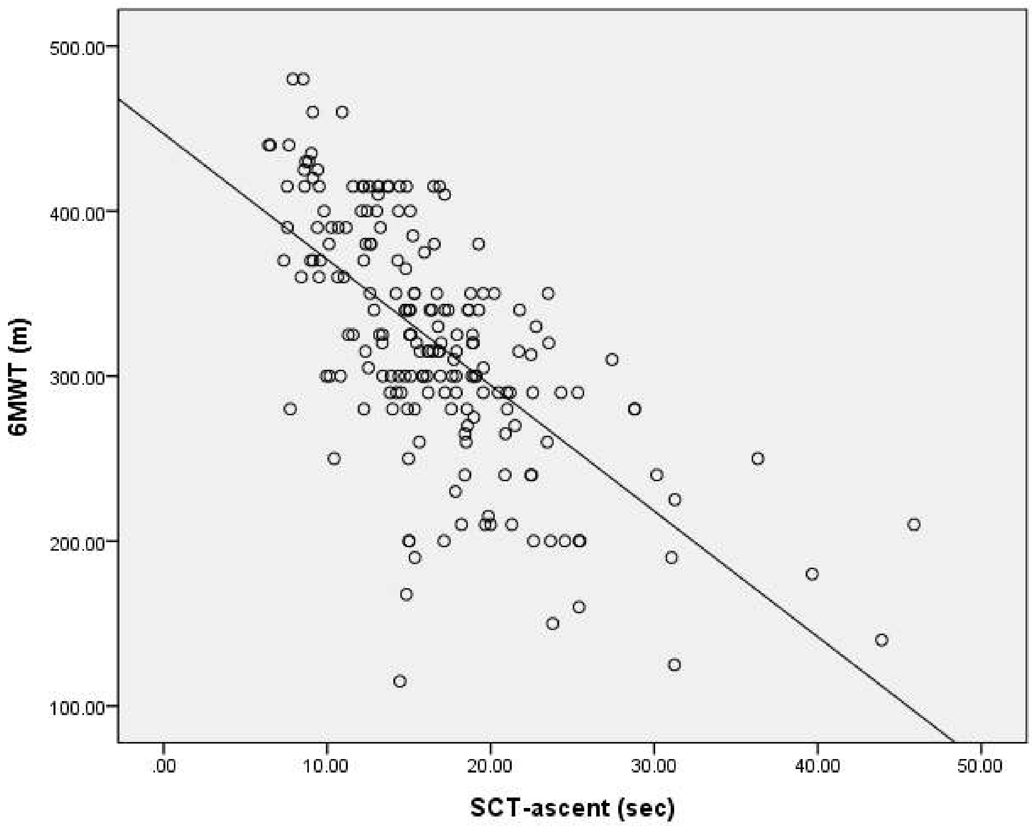


Figure 5(J). Correlation between gait endurance and SCT-ascent (r = -0.63, p < 0.001)

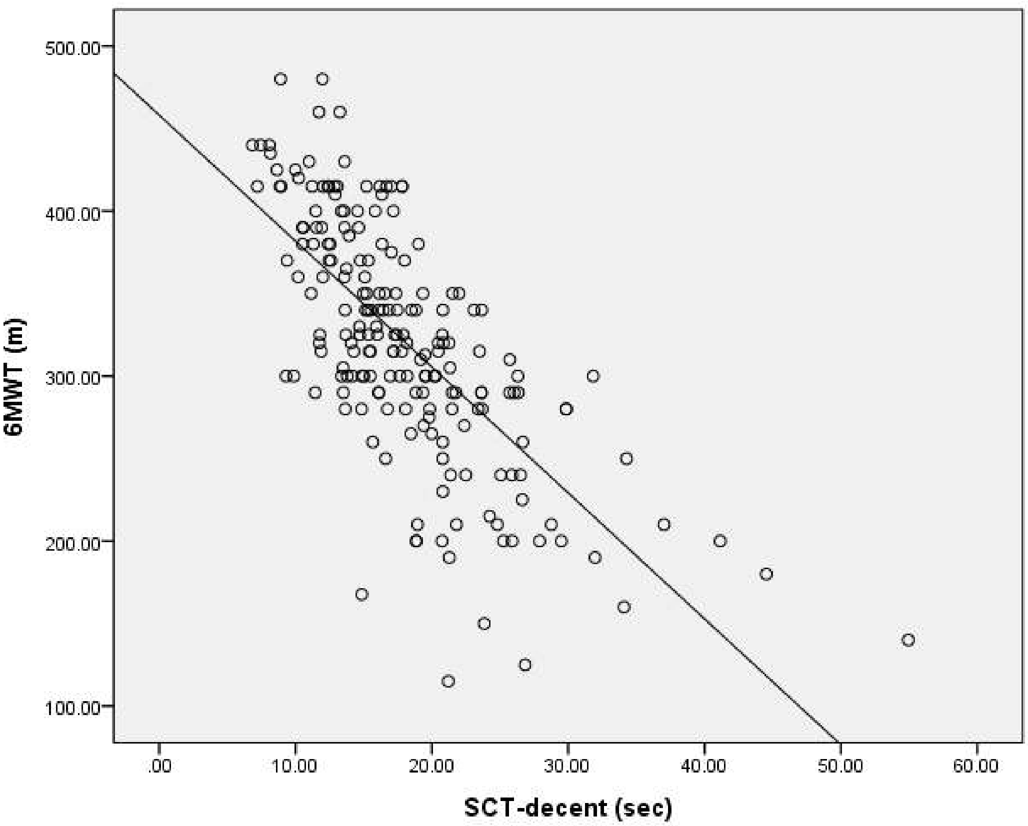


Figure 5(K). Correlation between gait endurance and SCT-descent (*r* = -0.68, *p* < 0.001)

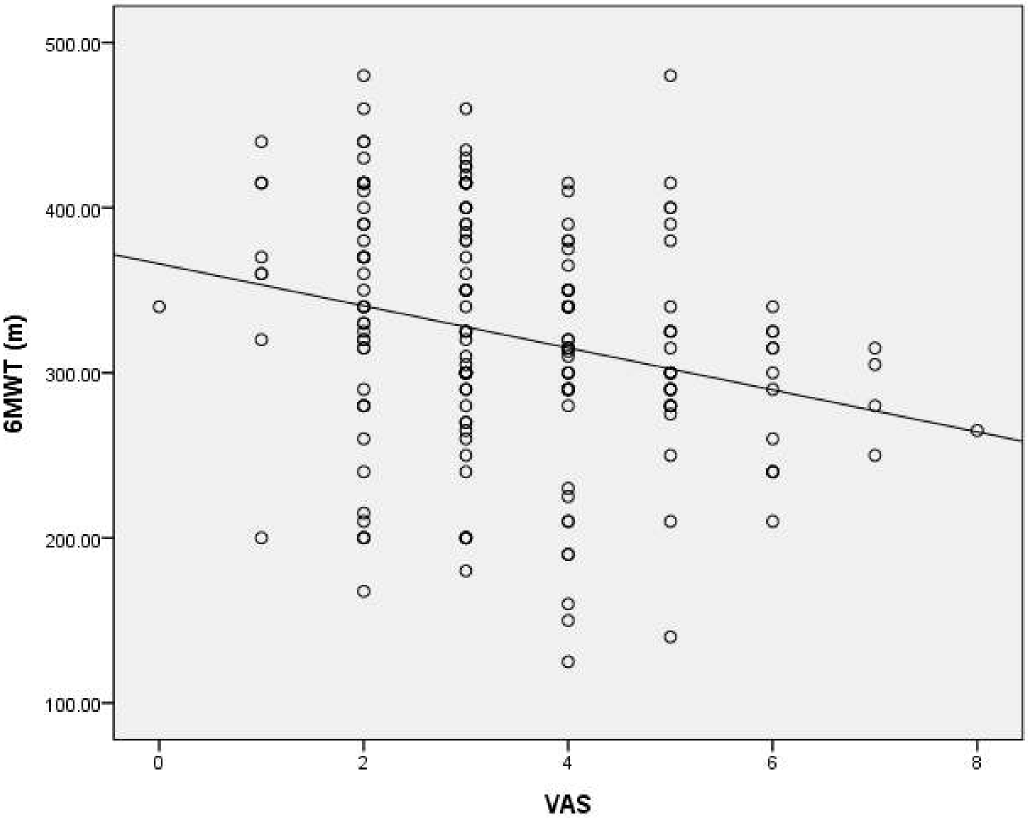


Figure 5(L). Correlation between gait endurance and VAS (r = -0.23, p = 0.001)

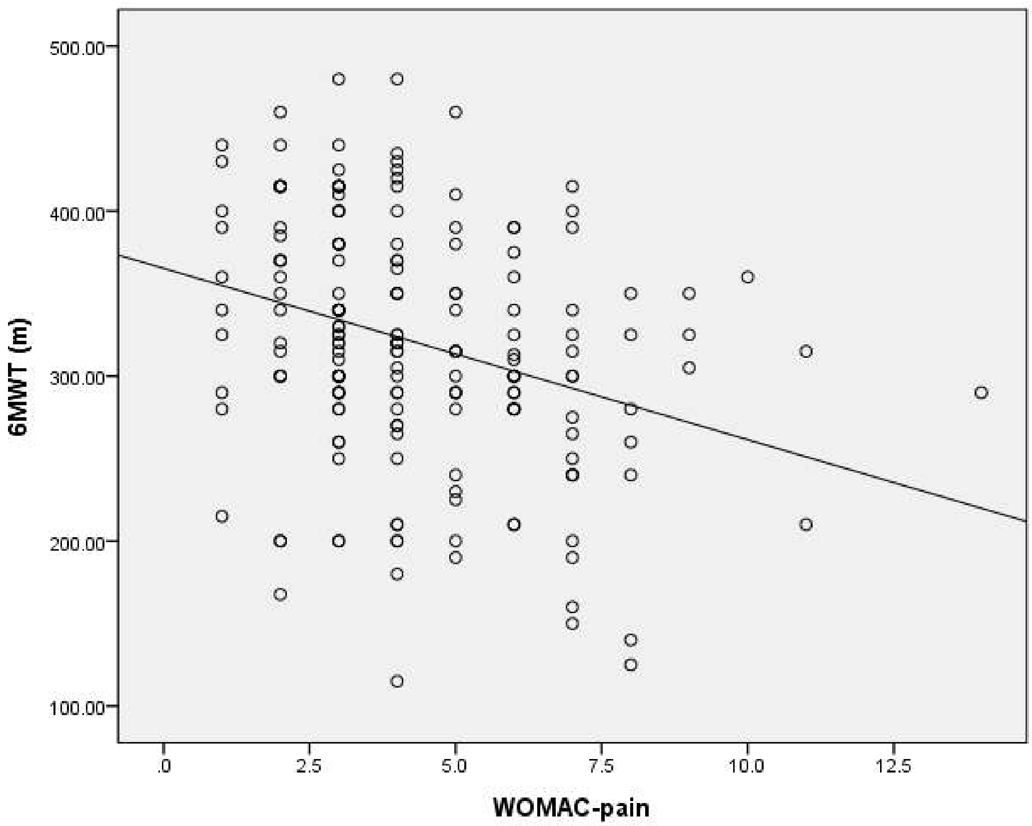


Figure 5(M). Correlation between gait endurance and WOMAC-pain (*r* = -0.29, *p* < 0.001)

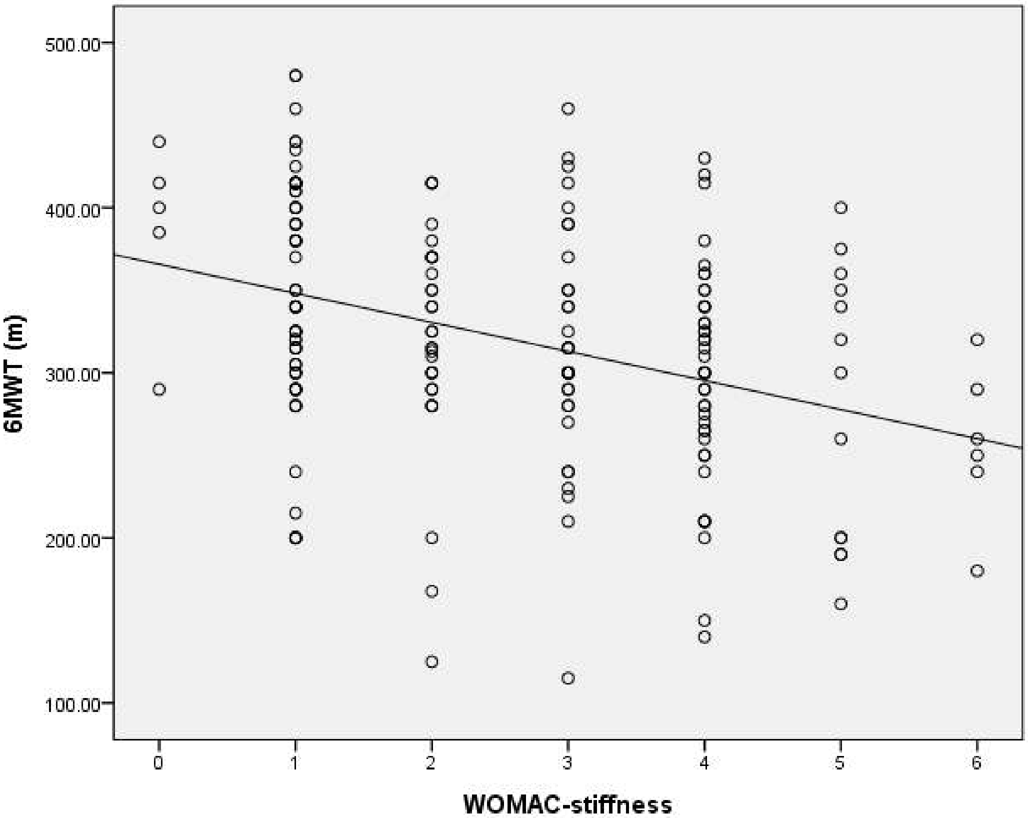


Figure 5(N). Correlation between gait endurance and WOMAC-stiffness

(r = -0.35, p < 0.001)

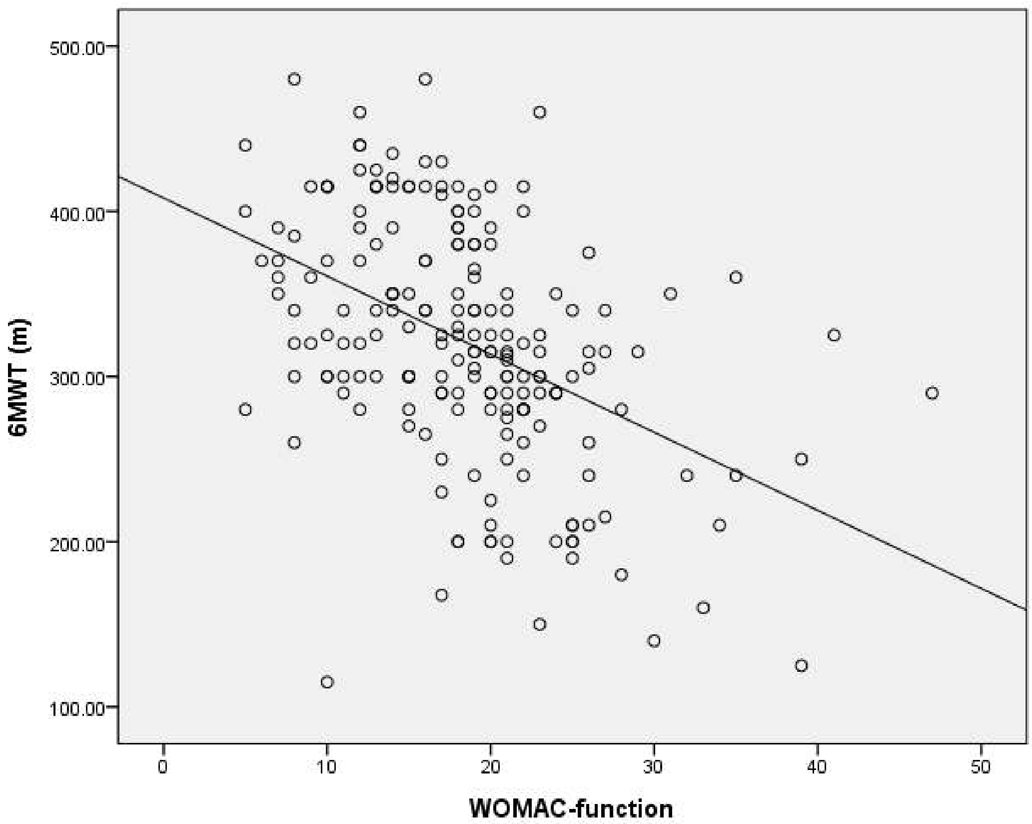


Figure 5(O). Correlation between gait endurance and WOMAC-function
(r = -0.43, p < 0.001)

After adjustments for demographics and anthropometric variables, a linear regression analysis showed that VAS ($\beta = -0.13$, $p = 0.03$) and the postoperative PT of the extensors of the surgical knee ($\beta = 0.15$, $p = 0.04$) and non-surgical knee ($\beta = 0.38$, $p < 0.001$) were factors associated with the postoperative gait endurance ($R^2 = 0.33$), as shown in Table 6.

Table 6. Factors correlated with Gait Endurance by Multivariate Linear Regression Analysis 1month after TKA

Outcome/Independent Predictor	Standardized β	*p*-value	Adjusted R^2
Gait endurance			
VAS	-0.13	0.03	0.33
PT extensor of surgical knee ($N \cdot m \cdot kg^{-1}$BW %)	0.15	0.04	
PT extensor of non-surgical knee ($N \cdot m \cdot kg^{-1}$BW %)	0.38	≤ 0.001	

Abbreviations: VAS, visual analog scale; PT, peak torque; BW, body weight

IV. DISCUSSION

We evaluated the objective performance-based physical function associated with gait speed and endurance after TKA in a large cohort of patients. The results demonstrated evidence for a significant association between gait function and objective performance-based physical functions, with the knee extensor muscle strength of both knees especially influencing the gait speed and endurance in the early period after TKA.

Deterioration of gait ability is important in patients with knee OA, as walking is one of the basic activities of daily life. Additionally, it leads to disabilities that interfere with locomotor function (Ouellet D et al., 2002). One study reported that severe cardiovascular deconditioning with chronic disability was observed in patients with severe knee OA (Philbin EF et al., 1995). Gait deterioration was associated with a progressive decline in functional activities and quality of life, as well as a high risk of coronary heart disease and cardiovascular disease. Ries et al. found that those patients who continued with routine functional activities demonstrated an improvement in cardiovascular fitness 1 year after TKA, with a significant improvement after 2 years (Ries MD et al., 1996). Deficits in gait ability and functional performance in comparison with pre-surgical values have been reported for the early period following TKA (Mizner RL et al., 2005). After TKA, decreases in quadriceps strength and physical performance are unavoidable in patients who have recently undergone surgery. Previous studies show a 60% decrease in quadriceps muscle strength and 17% decrease in voluntary muscle activation from preoperative levels 1 month after TKA (Mizner RL et al., 2005; Stevens JE et al., 2003). These conditions may lead to functional deficit. Mizner et al. reported 20–25% decreases in functional performance from pre-surgical values in the first month after TKA (Mizner et al., 2005). In addition, several studies have reported that 75% of patients have difficulty with climbing stairs and reductions in walking and stair-climbing speed after TKA relative to age-matched healthy controls (Bade MJ et al., 2010).

Researchers have therefore been trying to determine the factors affecting gait function as an outcome measure, including identification of those factors associated with a poor outcome through objective measurements of the condition of patients after TKA.

Recently, gait analysis has become increasingly attractive as an outcome measure of gait function after TKA, as it allows clear assessment of postoperative changes in gait, and has been recognized as a useful objective functional evaluation tool to define pathological changes to the knee, such as those that may occur in the post-TKA state. Senden et al. showed the clinical relevance of gait analysis as a functional assessment tool to identify and routinely monitor postoperative patients (Senden R et al., 2011). Through pre and postoperative monitoring of patients, gait parameters provide additional objective information about a patient's functional ability, providing feedback to therapists and physiatrists.

Among the different gait parameters, gait speed and endurance may be useful variables for assessing the functional effects of TKA and for monitoring recovery. A recent meta-analysis that investigated the effects of TKA on gait speed revealed an extensive effect 6 to 60 months after TKA (Abbasi-Bafghi H et al., 2012). Patients showed a slow improvement in gait speed for several months after surgery. However, gait speed limitations may persist after the first year, and patients often fail to reach healthy levels, even several years after TKA (Maxwell J et al., 2013).

Another factor commonly used to evaluate ambulatory capacity is the 6MWT (Yoshida Y et al., 2008), which measures the maximal distance a subject can walk in 6 minutes, and is a simple and clinically relevant measure of gait endurance. The 6MWT is a strong measure of functional mobility and is commonly used to evaluate functional recovery after TKA (Ko V et al., 2013). It can detect changes in both gait speed and endurance, whereas gait analysis over short distances assesses only speed. It also has the advantage that it demonstrates less variability than other gait analysis parameters. Consequently, it is necessary to investigate other gait parameters, including gait speed and endurance, to better understand the early functional effect after TKA.

In our study, the 195 patients had a mean gait speed of 1.0 m/s and a 6MWT of 320.0 m. This was slightly higher than the corresponding walking speed values of 0.86 m/s and the 6MWT of 255.4 m reported by other authors at 1 month after TKA (Pua YH et al., 2016; Bade MJ et al., 2010). Considering the substantial deficits in quadriceps strength and functional performance that occurred 1 month after surgery with standard rehabilitation (Bade MJ et al., 2010), our results could suggest that the intensive inpatient rehabilitation training methods used during the first two postoperative weeks in our study may have been helpful for improving gait speed and endurance soon after TKA. However, the recovery of gait parameters is generally not fully achieved at 1 month after TKA in comparison with age-matched healthy controls. Although there was no control group in our study, the gait speed and 6MWT values of our patients were lower than those of a previously documented age-related healthy reference group, which demonstrated a gait speed of 1.34 m/s and a 6MWT of 406 m (Chui KK et al., 2010; Lusardi MM et al., 2003). This suggests that more intensive therapeutic strategies may be necessary for TKA patients to facilitate the recovery of gait function to the levels of healthy people.

The first objective of this study was to identify those objective performance-based physical function factors that contribute to a patient's gait speed, and we showed that gait speed had a significant positive correlation with the postoperative PT of the extensors and flexors of both surgical and non-surgical knees, 6MWT, and negative correlation with TUG, SCT.

Quadriceps and other leg muscles produce a force that support the body's center of mass against gravity. Especially, the strength of quadriceps is associated with the knee extension moment in early stance phase of gait (O'Connel M et al., 2016). Thus, knee extension moment generally decreases in patients with knee OA (Zeni JA et al., 2011). They also have a different kinematic feature of knee joint excursion in early stance phase compared to healthy control. In normal gait, the knee gradually bended after an initial heel contact and turned to extend during early and mid-stance phases (Winter DA et al., 2009). But, in patients with OA, the knee is continuously flexed during early stance phase (Al-Zahrani K et al., 2002). The reduction of knee extensor moment results in a decrease in knee excursion and walking speed in patients with knee OA (Zeni JA et al., 2009). In patients following TKA, lower postoperative quadriceps strength was closely associated with lower gait speed as well (Pua YH et al., 2016).

Valtonen et al. revealed that knee flexor power was independently associated with gait speed in patients with knee OA (Valtonen AM et al., 2015). This is explained by the fact that the knee flexor muscle provides stability during walking in post-TKA patients.

Additionally, Mizner et al. suggested that non-surgical quadriceps strength may be a proxy indicator of functional status and could influence physical function independently (Mizner RL et al., 2011). In our study, the non-surgical-side quadriceps strength was correlated with gait speed. Thus, these results suggest the importance of rehabilitation directed toward the non-surgical knee muscle strength, as well as that of the surgical knee.

Large deficits in surgical knee muscle strength in the early period after TKA have been reported for both the knee extensor and flexor (Mizner et al., 2005). These thigh muscle weaknesses after TKA have been reported to be related to mobility limitations. Nobles et al. reported that 75% of patients have difficulty with climbing stairs and demonstrated reductions in post-TKA walking and stair climbing speed relative to age-matched healthy controls (Noble PC et al., 2005). Decrements in functional mobility and gait speed have a direct influence on TUG (Podsiadlo D et al., 1991), and have been shown to moderately correlate with the 6MWT in elderly people (Harada ND et al., 2005).

Our second objective was to determine which objective performance-based physical function factors affect the gait endurance of patients. We evaluated 6MWT as a measure of gait endurance and we found that the gait endurance was associated with postoperative PT of the extensors and flexors of both knees, TUG, and SCT. Yoshida et al. found that in post-TKA patients, the quadriceps strength in both knees correlated with greater distances in the

6MWT, and faster times on the TUG and SCT (Yoshida et al., 2008). Although no previous study has observed a direct relationship between the gait endurance and performance-based physical function factors in patients following TKA, Murphy et al. identified an association between gait endurance (6MWT) and functional mobility (TUG), with the 6MWT being positively associated with aerobic capacity (VO_2 max) in older adults with symptomatic knee OA (Murphy et al., 2013). This suggests that muscle weakness, functional mobility, and cardiovascular performance could potentially influence the distance walked. With consideration of these findings, our results have important clinical implications, in that strengthening of the quadriceps muscle could improve gait endurance, eventually leading to enhancement of aerobic capacity and functional mobility in TKA patients.

In general, at 2 months after surgery, the gait pattern of patients who underwent TKA showed decreases in speed, cadence, stride length, and single support phase time, and an increase in double support phase time (Ouellet D et al., 2002). This change in gait pattern may be due to adjustments by patients to regain a safe and stable gait post-surgery. Similarly, our study also showed cadence and stride length were positively correlated with gait speed and endurance.

Lower postoperative knee flexion and extension ROM were closely associated with lower gait speed (Pua YH et al., 2016). Orthopedic surgeons and patients tend to be mostly concerned about reductions to the ROM of the postoperative knee in the early period after TKA. A fixed flexion deformity of the knee cause continuous contraction of the quadriceps to avoid buckling, which results in excessive energy consumption and fatigue. A previous study reported that a 15° flexion contracture produces 22% more contraction of the quadriceps than fully extended knee, and 30° flexion contracture led to 50% more contractions (Perry J et al., 1975). Therefore, patients with flexion contracture feel tired in daily activities such as standing, walking and stair climbing due to increased contraction of their quadriceps. Eventually, it led to a decrement of gait speed and abnormal gait posture. In fact, the walking speed showed a linear fashion of decrement in patient with flexion contracture between 15° and 20° (Harato K et al., 2008). And residual flexion contracture after TKA related to poor functional scores and outcomes (Harato K et al., 2008).

However, our results showed that the knee flexion and extension ROM did not significantly affect gait speed or endurance at 1 month after TKA. In this study, the average angle of knee flexion was 110° and extension angle was -5.8°. These results suggest that the ROM does not associate with gait function, provided that the knee ROM reaches the flexion angle of 67° required for walking. We also suggest that knee flexion contracture was not severe enough to influence gait function.

Finally, the multivariate linear regression analysis showed that VAS and the knee extensor muscle strength in both knees were significantly correlated with gait speed and endurance. It may be possible to explain postoperative gait function by measuring knee extensor muscle strength of both surgical and non-surgical knees early after TKA. Consequently, this suggests that the rehabilitation strategy in the early period after TKA should focus on pain reduction and strengthening of the knee extensor muscles of both surgical and non-surgical knees to improve gait ability and functional outcome.

Limitations

There are several limitations to the present study. Firstly, this study was a cross-sectional analysis without a follow-up. It was not possible to monitor changing patterns in the basic and follow-up values. Secondly, it may be difficult to estimate outcome and form a conclusion because one month after TKA is too early. However, this study tried to manage the variables that affect the patient's functional status such as postoperative pain, edema, and other complications which may be seen early after surgery.

Thirdly, the causal relationships of variables were not analyzed, as this study was a cross-sectional design without a control group. However, further prospective and experimental studies are being conducted in our cohort to determine the recovery process at 3, 6 and 12 months after TKA. The results will be collected along with those from a control group, and analyzed with respect to the causal relationships between the variables and the effects of our intensive rehabilitation.

V. CONCLUSION

This study demonstrated that evidence for a significant association between gait function and objective performance-based physical functions. In addition, quadriceps muscle strength of both surgical and non-surgical knees were an important explanatory factor for functional recovery after TKA, as reflected by gait speed and endurance in the early postoperative period. These findings suggest that rehabilitation strategies focusing on improvement of knee extensor strength in both surgical and non-surgical knees, as well as pain control, could be helpful for the recovery of gait function in the early stages following TKA.

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VII. ABSTRACT IN KOREAN

일측 슬관절 전치환술 환자에서 술 후 1개월째 보행 속도 및 지구력과 양측 대퇴사두근 근력의 연관성에 대한 단면 연구

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목적: 본 연구는 일측 슬관절 전치환술 후 1개월째 환자에서 객관적 기능 수행 기반 능력지표와 보행 기능의 상관관계를 확인하고자 하였다

방법: 본 연구는 후향적 단면 연구로, 총 195명의 일측 슬관절 전치환술을 받은 환자들이 연구에 모집되었다. 모든 피험자는 술 후 2주째 재활의학과로 전과하였고, 2주간의 재활 프로그램을 진행하였다. 수술측과 비수술측 슬관절 신전근과 굴곡근에 대한 등척성 근력평가, 보행 분석, 6분 걷기 (6MWT) 검사, Timed up and go (TUG) 검사, 계단 오르내리기 (SCT-ascent, descent) 검사, 수술측 슬관절 굴곡 및 신전 각도, Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) 와 EuroQol-5 Dimension (EQ-5D), 시각적 통증등급 (VAS)를 이용한 통증 척도가 술 후 1개월째 평가되었다.

결과: 총 195명의 일측 슬관절 치환술을 시행한 환자들에서 이변량 상관분석을 시행하였으며 수술측 슬관절 신전근 ($r = 0.35$, $p < 0.001$), 비수술측 슬관절 신전근 ($r = 0.43$, $p < 0.001$), 수술측 슬관절 굴곡근 ($r = 0.22$, $p < 0.001$), 비수술측 슬관절 굴곡근 ($r = 0.21$, $p = 0.003$) 의 체중에 대한 최대 우력, 6MWT, 보속 수와 보행 시간이 술 후 보행 속도와 양의 상관관계를 보였다. TUG, SCT, VAS, WOMAC-pain, stiffness, function 점수는 보행 속도와 음의 상관관계를 보였다. 수술측 슬관절 신전근 ($r = 0.36$, $p < 0.001$), 비수술측 슬관절 신전근 ($r= 0.49$, $p < 0.001$), 수술측 슬관절 굴곡근 ($r = 0.25$, $p < 0.001$), 비수술적 슬관절 굴곡근 ($r = 0.34$, $p < 0.001$) 체중에 대한 최대 우력, 보행 속도, 보속 수와 보행 시간, EQ-5D 점수는 술 후 보행 지구력과 양의 상관관계를 보였다. TUG, SCT, VAS, WOMAC-pain, stiffness, function 점수는 술 후 보행 지구력과 음의 상관관계를 보였다.

다변량 선형 회귀분석 결과, 술 후 1개월째 보행 속도와 수술측 슬관절 신전근 근력 ($\beta = 0.16$, $p = 0.04$), 비수술측 슬관절 신전근 근력 ($\beta = 0.27$, $p < 0.001$), VAS ($\beta = -0.15$, $p = 0.03$) 점수가 유의한 상관관계를 나타냈으며, 술 후 1개월째 보행 지구력과 수술측 슬관절 신전근 근력 ($\beta = 0.15$, $p = 0.04$), 비수술측 슬관절 신전근 근력 ($\beta = 0.38$, $p < 0.001$), VAS ($\beta = -0.13$, $p = 0.03$) 점수가 유의한 상관관계를 보였다.

결론: 일측 슬관절 치환술을 시행한 환자에서 술 후 1개월째 수술측과 비수술측 대퇴사두근 근력이 보행 속도 및 지구력과 유의한 상관성이 있음을 알 수 있었다.

VIII. APPENDICES

<Appendix 1>

본인의 건강상태 평가 (EQ-5D)
아래의 문항에서 오늘 귀하의 건강 상태를 가장 잘 설명해주는 하나의 항목에 표시해 주십시오.

1. 운동 능력
   나는 걷는데 지장이 없다 □ 1
   나는 걷는데 다소 지장이 있다 □ 2
   나는 종일 누워 있어야 한다 □ 3

2. 자기관리
   나는 목욕을 하거나 옷을 입는데 지장이 없다 □ 1
   나는 혼자 목욕을 하거나 옷을 입는데 다소 지장이 있다 □ 2
   나는 혼자 목욕을 하거나 옷을 입을 수가 없다 □ 3

3. 일상 활동 (예 : 일, 공부, 가사일, 가족 또는 여가 활동) □ 1
   나는 일상 활동을 하는데 지장이 없다 □ 2
   나는 일상 활동을 하는데 다소 지장이 있다 □ 3
   나는 일상 활동을 할 수가 없다

4. 통증/불편
   나는 통증이나 불편감이 없다 □ 1
   나는 다소 통증이나 불편감이 있다 □ 2
   나는 매우 심한 통증이나 불편감이 있다 □ 3

5. 불안/우울
   나는 불안하거나 우울하지 않다 □ 1
   나는 다소 불안하거나 우울하다 □ 2
   나는 매우 심하게 불안하거나 우울하다 □ 3

<Appendix 2>

한글판 WOMAC 지수						
구분	항목과 평가내용	평가				
	통증	불편하지 않다	조금 불편하다	보통이다	많이 불편하다	매우 많이 불편하다
1	걷기					
2	계단 오르기					
3	야간					
4	휴식					
5	체중부하					
	경직	불편하지 않다	조금 불편하다	보통이다	많이 불편하다	매우 많이 불편하다
1	아침 경직					
2	낮 동안의 경직					
	신체적 기능	불편하지 않다	조금 불편하다	보통이다	많이 불편하다	매우 많이 불편하다
1	계단 내려오기					
2	계단 올라가기					
3	앉은 자세에서 일어나기					
4	서기					
5	무릎 굽히기					
6	평지 걷기					
7	자동차 타기와 내리기					
8	쇼핑가기					
9	양말신기					
10	침대에서 일어나기					
11	양말벗기					
12	침대에 눕기					
13	욕조에 들어가기와 나오기					
14	앉기					
15	화장실에 들어가기와 나오기					
16	힘든 집안일					
17	가벼운 집안일					