

Gait Symmetry and Walking Speed Analysis Following Lower-Extremity Trauma

Background and Purpose. Gait has been shown to be a major determining factor of function following limb-salvage surgery. However, little is known regarding the measures associated with gait recovery for this patient population. The purpose of this study was to identify clinical measures associated with impaired walking speed and gait asymmetry in patients with lower-extremity reconstruction. **Subjects.** Study subjects were 381 patients from the Lower Extremity Assessment Project (LEAP) who had undergone reconstruction following severe lower-extremity trauma. **Methods.** The LEAP study was a longitudinal study of outcomes following lower-extremity reconstruction. The present study used 24-month clinical follow-up data. A combined outcome measure of reduced walking speed and gait deviation was chosen to provide a comprehensive measure of impaired physical mobility. **Results.** The most significant clinical factors associated with decreased walking speed and gait deviation were impaired ankle plantar-flexion range of motion, knee flexion strength, and a nonreciprocal stair-climbing pattern. **Discussion and Conclusion.** The findings provide clinicians with specific clinical measures associated with functional recovery in patients with lower-limb reconstruction. These measures, in turn, can be considered to inform treatment decision making and to prioritize interventions. [Archer KR, Castillo RC, MacKenzie EJ, Bosse MJ; LEAP Study Group. Gait symmetry and walking speed analysis following lower-extremity trauma. *Phys Ther.* 2006;86:1630–1640.]

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Lower-extremity salvage procedures have become widespread, and limbs once amputated are now routinely treated with complicated reconstruction.^{1,2} One of the primary outcomes in limb-salvage rehabilitation is the recovery of functional gait.³⁻⁶ Currently, the most widely used informal measures are walking speed, gait symmetry, and stride duration.^{3-5,7-10} Although there is extensive literature on limb function and the reorganization of gait after amputation, relatively little is known about the limb-salvage recovery process.

Rehabilitation of people with lower-extremity reconstruction typically ranges from 12 to 72 months, with a median recovery time of 30 months.¹¹ Smaller studies (<40 subjects) that have examined the recovery of gait have demonstrated that a slower preferred walking speed, a lengthened stride time, a deterioration of balance control, and an involvement of the knee joint are associated with longer salvage recovery times.^{4,11,12}

One study⁶ showed that poor muscle strength (force-generating capacity) was correlated with abnormal gait, as well as the significant prognostic factors of increasing age and female sex. In salvages from bone tumors, decreased knee extensor strength was associated with a step-to-step (nonreciprocal) stair-climbing pattern, decreased locomotion, and compensatory hip and ankle movement strategies.⁵ Research suggests that muscle power is a primary determinant of gait,^{6,13,14} and manual muscle testing is a common clinical assessment tool for patients with lower-extremity trauma. The functional role, optimal strength, and optimal range of motion (ROM) of the hip, knee, and ankle have been well documented for normal gait, but the association of these measures with the recovery of gait among patients with limb salvage remains questionable.

The purpose of this study was to identify clinical measures associated with gait asymmetry and impaired walking speed in patients with lower-extremity reconstruc-

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tion. The attainment of independent and unimpaired ambulation is an essential element of rehabilitation for lower-extremity trauma. Based on prior limb-salvage research, we hypothesized that increasing age, nonreciprocal stair-climbing ability, poor single-leg balance, and a manual muscle test (MMT) grade of less than 4 for hip extension, knee extension, ankle dorsiflexion (DF), and ankle plantar flexion (PF) would be statistically associated with gait deviation and walking speeds of less than 4 ft/s (1 ft/s=0.30 m/s). Understanding the association of strength, ROM, and functional measurements with impaired physical mobility in patients with lower-limb reconstruction will assist clinicians with establishing effective plans of care and help inform treatment decision making and prioritization of interventions.

Method

Design and Subjects

In the present study, we used 24-month follow-up data collected as part of a larger, multicenter study, the Lower Extremity Assessment Project (LEAP). The LEAP study was originally designed to determine functional outcomes of patients with severe lower-extremity trauma resulting in reconstruction or amputation. A total of 601 patients, 16 to 69 years of age, were enrolled between March 1994 and June 1997 from 8 level I trauma centers (Carolinas Medical Center, Cleveland MetroHealth Medical Center, Harborview Medical Center, North Carolina Baptist Hospital, R Adams Cowley Shock Trauma Center, Tampa General Hospital, University of Texas Southwestern Medical Center, and Vanderbilt University Medical Center).¹⁵ *Lower-extremity trauma* was defined as complex fractures (Gustilo grade IIIB and IIIC fractures, selected grade IIIA fractures),¹⁶ dysvascular limbs, major soft tissue injuries to the tibia (degloving or severe crush or avulsion injury), or severe foot and ankle injury.¹⁷ Exclusion criteria included the following: a score of less than 15 on the Glasgow Coma Scale on admission, spinal cord deficits, prior amputation, third-degree burns, inability to speak English or Spanish, documented psychiatric disorder, and active military duty.¹⁷

The current analysis excluded 32 patients with bilateral injuries and 161 patients treated by amputation. An additional 27 patients were lost to follow-up at 24 months, resulting in 381 subjects with lower-limb reconstruction. Patients lost to follow-up were more likely to be of lower socioeconomic status than those with complete follow-up.¹⁷ Lower-extremity reconstruction surgery was performed primarily as a result of complex tibia fractures (51%), with the remaining 30% performed following severe foot and ankle injuries (Gustilo grade IIIB ankle fractures, all grade III intra-articular fractures of the distal tibia) and 18% following dysvascular injuries

(knee dislocations, closed fractures of the tibia, or penetrating wounds with vascular injury).^{15,17} Injury characteristics included articular involvement (35%), nerve damage (6%), moderate-to-severe muscle damage (48%), and bone loss greater than 2 cm (21%). The mean age of the primarily male (75%) subjects was 35.6 years (SD=12.3). The majority of the participants were white (71%) and had less than a grade 12 education (69%).

Outcome

This study was primarily interested in the recovery of functional gait, as measured by gait speed and symmetry. Walking speed of ≤ 4 ft/s and gait deviation were combined into one primary outcome measure. This combined measure was used not only to provide an indication of impaired physical mobility,¹⁸ but to reflect a subject's poor quality of movement.¹⁹ Below we describe how walking speed and gait deviation were evaluated in the LEAP study and how these evaluations were combined into one primary outcome measure.

Walking speed. Subjects were asked to walk 150 ft (45.7 m) on a level surface "as fast as they can" without an assistive device. The time it took for subjects to complete the task was measured with a stopwatch and recorded as feet per second. The use of a stopwatch has been found to yield data with excellent concurrent validity with the gold standard of infrared timing gates and an intraclass correlation coefficient (ICC) of at least .998 for tests of walking speed.²⁰ No other reliability testing was conducted on this measure.

Gait deviation. Subjects who participated in the 150-ft independent walking test also were visually monitored for gait deviations. Physical therapists were provided with a detailed description of each deviation. Participants were found to have gait asymmetry if they had one or more of the following common deviations: Trendelenburg gait, trunk asymmetry, leg circumduction, hip hike (increased hip abduction on the unaffected stance limb, with simultaneous pelvic elevation on the affected side during swing), knee hyperextension, no heel-strike, toe drag, uneven step length, or a limp not accounted for by the other listed deviations. Observational techniques have been found to yield data with moderate reliability,²¹⁻²³ while instrumented gait analysis is the criterion standard.²⁴ However, a 3-dimensional technique was impractical and too costly for the present study.

Walking speed and gait deviation. A walking speed of 4 ft/s or less was considered an appropriate cutoff for impaired speed because the literature recognizes acceptable walking speeds of 3.2 ft/s for patients with lower-limb salvage 15 months postinjury and speeds ranging from 4.07 to 4.2 ft/s for fully recovered patients with

transtibial and below-knee amputations.^{3,25,26} Mean walking speeds for individuals without gait impairments range from 4.4 to 4.9 ft/s, depending on age, sex, and location of ambulation.²⁷⁻²⁹ A walking speed cutoff of 5 ft/s also was examined to confirm associations between selected clinical variables and the primary outcome measure.

Potential Clinical Factors Associated With Abnormal Gait

A number of common impairment and functional measures were used as assessment tools to examine the factors associated with abnormal gait. We will describe these measures along with their scales and scoring systems.

Self-report pain scale. Pain level was assessed with a visual analog scale (VAS), using a 0- to 100-mm horizontal line. Participants were asked to rate their average daily leg pain by placing a mark on the line between “no pain” on the left and “unbearable pain” on the right. The VAS score was recorded by measuring the distance from the “no pain” end of the line to the participant’s mark of personal pain intensity. A distance of 5 to 44 mm was considered mild pain, 45 to 74 mm was considered moderate pain, and 75 to 100 mm was considered severe pain.³⁰

Stair-climbing and balance performance. Gait capacity can be estimated by a person’s ability to go up and down stairs with a step-by-step (reciprocal) maneuver.⁵ Participants were asked to climb 12 steps and then descend the same 12 steps at their preferred speed. A physical therapist noted whether the subject displayed a step-by-step pattern or a nonreciprocal, step-to-step pattern for both ascending and descending tasks.

Two parameters were used for standing balance: unilateral (single-leg) and tandem stance. For unilateral stance, subjects were asked to stand on one leg with their eyes open and arms crossed across their chest for 30 seconds. The number of seconds that the subject was able to stand before dropping the other leg was recorded for both the involved and uninvolved legs. Subjects were scored from 0 to 30 seconds. They then were asked to stand unsupported for 10 seconds with their eyes closed, arms crossed across their chest, and their injured foot touching the heel of their other foot. A score of less than 30 seconds for the unilateral stance and less than 10 seconds for the tandem stance was defined as functionally poor.³¹⁻³³ A score of 0 seconds was attributed to subjects being unable to perform either of the 2 balance tasks.

Girth measurements. Thigh and calf girth measurements were used to assess muscle atrophy.³⁴ Circumferential measurements have been found to have high

intrarater reliability and interrater reliability, with ICCs of .82 and .72, respectively.³⁵ Data were recorded with a tape measure using the following landmarks: 8 cm proximal to the superior patella with knee in extension and 8 cm distal to the tibial tuberosity. Muscle atrophy of 0 cm, 1 to 2 cm, or 3 cm or greater was determined by comparing each subject’s data for the involved leg with data for the uninvolved leg.

Range of motion. Hip flexion and extension, knee flexion, and ankle DF and PF were measured using a standard goniometric technique.³⁶ Subjects were asked to remove their shoes and socks and actively move the joint through the desired range. Physical therapists recorded the active range of motion (AROM) with the subjects positioned supine and then prone using a universal goniometer; measurements were rounded up to 5 for 3’s and 4’s and rounded down to 0 for 1’s and 2’s. Studies of the universal goniometer have shown high intrarater reliability for knee and ankle ROM, with ICCs for knee flexion and extension ranging from .97 to .99 and ICCs for ankle PF and DF ranging from .82 to .86.^{37,38} Starting and ending positions of each joint, as recommended by the American Academy of Orthopaedic Surgeons (AAOS),³⁹ were used to record measurements. Norms were determined based on the averages published by the AAOS; ROMs below 120 degrees of hip flexion, 30 degrees of hip extension, 135 degrees of knee flexion, 20 degrees of ankle DF, and 50 degrees of ankle PF were considered restricted.

Strength. Hip flexion, extension, and abduction; knee flexion and extension; and ankle DF and PF strength were measured by a patented device for exercising and measuring strength of a person’s limb.⁴⁰ The strength apparatus includes a pair of pivot clamps that were used to connect it to a physical therapy table. The pivot clamps enabled rotational and translational movement of the frame, which allowed the frame to be positioned in a desired location and orientation relative to the limb being tested. Subjects were asked to apply maximal force against the force plates in the direction of the desired movement. A force transducer produced an output that represented each subject’s force, and the output was displayed on a digital panel meter. A force gauge has been found to measure strength more reliably and accurately than manual muscle testing.

Three measurements of each motion were recorded for both the involved and uninvolved limbs. The maximum effort was selected, and the ratio of the injured limb to the uninjured limb for each motion was calculated. The ratio scores were separated into 2 categories: less than 50% and greater than 50%. Because manual muscle testing⁴¹ is a more widely used measure and the MMT scale of 0 to 5 is clinically meaningful,⁴² the ratio

categories were translated into MMT grades with the use of the percentage scores of Kendall and McCreary.⁴³ Normal strength or an MMT grade of 5 corresponds to a joint motion ratio of greater than 81%, a ratio of 51% to 80% is considered grade 4, a ratio of 21% to 50% is considered grade 3, and a ratio of 20% or less is considered grade 2.^{43,44} An MMT grade of 4 is considered an average or good score, and an MMT grade of less than 4 indicates fair or even poor strength.⁴¹ Because a good score is considered a necessity for fast walking,⁴⁵ subjects in this study with an MMT grade of less than 4 were considered to have impaired strength.

An additional variable of toe raises was used to measure functional ankle PF strength of the involved and uninvolved legs.⁴¹ The number of times a subject performed full-excision toe raises within 15 seconds, while keeping the knee straight and using one hand for support, was recorded.^{41,46} If a subject was unable to perform a toe raise, then a score of zero was recorded for that subject. A normal score was 10; a score of less than 10 was considered functionally impaired.³³

Data Analysis

Data analysis and interpretation of results were performed using Stata statistical software, version 8.0.* Bivariate relationships between demographic and clinical variables and outcome measures were assessed using chi-square tests for binomial data and Student *t* tests for continuous data.

The main goal was to develop a multivariate logistic regression model of clinical measures correlating with gait deviation and impaired walking speed 2 years following major lower-extremity trauma treated by reconstruction. Separate analyses were conducted for gait deviation and walking speed at ≤ 4 ft/s and for gait deviation and walking speed at ≤ 5 ft/s. Each analysis was conducted in 4 phases. First, a bivariate logistic regression analysis was performed to assess the relationship between potential variables and the combined outcome of gait deviation and decreased walking speed. Second, an initial multivariate logistic regression analysis was conducted with all baseline sociodemographic characteristics and clinical variables. The results of the multivariate and bivariate logistic regression analyses were compared to ensure that no covariates had been incorrectly dropped from the analysis, and the presence of interactions and correlations between impairment and functional measures was investigated. Third, clinical factors with *P* values less than or equal to .10 using the Wald test were selected for additional analysis. These variables were confirmed with stepwise regression and goodness-of-fit techniques. Fourth, a final multivariate

logistic regression analysis was performed with variables that were statistically significant at the $P < .10$ level or if removal of the variable resulted in substantial changes in the magnitude of other variables in the model. Data for subjects who were missing specific data points were kept in the analysis by using missing data categories, but these categories are not presented.

Results

Information on gait deviation and walking speed was available on 277 (73%) of the eligible 381 patients with lower-limb reconstruction. Subjects with incomplete outcome data were significantly more likely to be 45 years of age or older ($P < .05$) and without a high school education ($P < .01$). Participants were found to have the following deviations: Trendelenburg gait (8%), trunk asymmetry (10%), leg circumduction (6%), hip hike (8%), knee hyperextension (3%), no heel-strike (7%), toe drag (13%), uneven step length (20%), and a noticeable limp not accounted for by one of the other deviations (12%). The subjects' mean walking speed for 150 ft was approximately 4.7 ft/s (SD=1.9).

The distributions of demographic and injury characteristics and clinical variables by outcome are presented in Tables 1 and 2. The bivariate associations between the primary outcome and these clinical measures 24 months after reconstruction are shown in Table 3. Nonreciprocal stair-climbing pattern, < 30 seconds of unilateral stance, < 10 seconds of tandem standing balance, < 10 toe raises, ≥ 3 cm of calf atrophy, < 120 degrees of hip flexion ROM of the involved limb, < 50 degrees of ankle PF ROM of the involved limb, < 20 degrees of ankle DF ROM of the involved limb, and all strength measures with an MMT grade of < 4 , except hip abduction, were independently related to gait deviation and decreased walking speed at $P < .05$. After adjusting for age, insurance, and injury, only a nonreciprocal stair-climbing pattern, impaired unilateral stance, decreased hip extension and knee flexion strength, and limited ankle PF ROM of the involved limb remained significantly associated with impaired physical mobility ($P < .10$).

From the final multivariate logistic regression model, the most significant factors associated with gait deviation and walking speed of ≤ 4 ft/s for subjects with lower-limb reconstruction were < 50 degrees of PF ROM of the involved ankle, nonreciprocal stair climbing, and knee flexion strength with an MMT grade of < 4 at $P < .05$ (Tab. 4). In addition, these associations were further confirmed with a multivariate logistic regression of gait deviation and walking speed of ≤ 5 ft/s.

Discussion

As expected, we found a significant association between pathological gait and age, nonreciprocal stair-climbing

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Table 1.

Baseline Demographic and Injury Characteristics of Study Sample by Main Outcome at 24 Months (N=381)

Variable	n	Gait Deviation	Walking Speed ≤4 ft/s	Gait Deviation and Walking Speed ≤4 ft/s
Age (y)				
0-24	82	51%	19%	21%
25-34	106	48%	20%	17%
35-44	105	53%	44%	30%
≥45	88	63%	43%	38%
Sex				
Male	285	54%	30%	25%
Female	96	53%	38%	32%
Race/ethnicity				
White	271	53%	34%	28%
Black	80	52%	31%	24%
Hispanic	19	58%	8%	8%
Other	11	67%	33%	33%
Education (y)				
<12	262	55%	32%	24%
≥12	119	51%	32%	31%
Insurance				
None	146	48%	32%	24%
Medicaid	25	59%	35%	29%
Medicare	4	67%	0%	0%
Health maintenance organization	46	55%	25%	22%
Commercial	148	59%	34%	32%
Other	12	33%	33%	11%
Injury				
Dysvascular	70	52%	30%	22%
Foot/ankle/tibia	114	49%	26%	21%
Tibial fractures	197	57%	37%	32%
Articular involvement				
No	246	38%	22%	18%
Yes	135	41%	26%	21%
Nerve damage				
No	358	38%	23%	19%
Yes	23	52%	30%	30%
Muscle damage				
Mild	198	37%	24%	19%
Moderate-severe	183	41%	23%	20%
Bone loss				
<2 cm	301	38%	22%	19%
≥2 cm	80	41%	27%	22%

ability, and poor single-leg balance. Age has previously been found to be a significant predictor of poor gait ($P<.001$) and overall limb function ($P<.002$) in patients with limb salvage.⁶ The literature discusses stair-climbing ability as an estimate of gait capacity^{5,8} and balance control as an area of clinical concern,^{3,47} but our study is the first study to show a statistically significant correlation between abnormal gait and both nonreciprocal stair-climbing pattern and poor single-leg balance of the involved and uninvolved limbs. Balance has been

examined more thoroughly in patients with lower-limb amputation, with one study finding single-leg balance of the uninvolved limb to be a significant predictor of functional outcome in elderly people with amputations.³¹

Studies of gait recovery after limb-saving surgery secondary to malignant bone tumors and trauma have consistently shown an association between decreased knee extension strength and increased asymmetry and decreased walking speed.^{3,5,11} The association between knee extensor strength and impaired gait directly relates to the extent of quadriceps femoris muscle excision during the tissue and bone resection process of tumor surgery^{3,48} and the resulting quadriceps femoris muscle atrophy in patients with traumatic reconstruction.¹¹ In this study of patients with traumatic lower-extremity reconstruction, decreased knee extension strength and thigh atrophy were not significantly associated with gait deviation and decreased walking speed. We found that only 24% of the subjects had a knee extension MMT grade of <4 and 18% had thigh atrophy of ≥3 cm. The limited quadriceps femoris muscle involvement in this patient population can be attributed to their distribution of injury characteristics. The majority of the reconstruction surgeries were due to tibia fractures (51%) and severe foot and ankle injuries (40%), where excision of the quadriceps femoris muscle is not common.

Instead, impaired knee flexion strength was found to be significantly associated with pathological gait. Approximately, 72% of the subjects with impaired knee flexion strength had a gait deviation, and 50% had a gait deviation and a walking speed of ≤4 ft/s. This high percentage of gait deviation is consistent with the functional role of the knee during ambulation. The knee absorbs energy during the stance phase of gait and is mainly involved with smoothing the gait pattern.⁴⁹ A smaller contribution is made to walking speed by the biceps femoris muscle, which flexes the knee during the swing phase to assist with flexion velocity as well as smooth foot clearance.⁴

Table 2.
Clinical Variables of Study Sample at 24 Months by Main Outcome (N=381)^a

Clinical Variable	n	Gait Deviation	Walking Speed ≤4 ft/s	Gait Deviation and Walking Speed ≤4 ft/s
VAS for pain				
No pain	57	32%	23%	21%
Mild pain	158	55%	29%	24%
Moderate-severe pain	73	66%	44%	37%
Ascend stairs				
Reciprocal	212	48%	23%	20%
Nonreciprocal	74	69%	57%	45%
Descend stairs				
Reciprocal	186	46%	21%	18%
Nonreciprocal	100	68%	52%	42%
Unilateral stance: involved side				
≥30 s	83	34%	7%	6%
<30 s	204	62%	42%	35%
Unilateral stance: uninvolved side				
≥30 s	183	50%	20%	18%
<30 s	104	61%	53%	42%
Tandem standing balance				
≥10 s	108	41%	13%	15%
<10 s	179	61%	44%	34%
Toe raises: involved side				
≥10	86	27%	8%	7%
<10	199	65%	43%	35%
Toe raises: uninvolved side				
≥10	141	43%	22%	19%
<10	144	65%	43%	34%
Thigh atrophy				
0 cm	118	48%	31%	24%
1-2 cm	114	56%	30%	26%
≥3 cm	51	62%	39%	33%
Calf atrophy				
0 cm	122	47%	28%	25%
1-2 cm	90	49%	20%	17%
≥3 cm	71	70%	54%	41%
Hip flexion ROM: involved side				
≥120°	266	51%	30%	51%
<120°	24	83%	56%	83%
Hip flexion ROM: uninvolved side				
≥120°	275	52%	31%	26%
<120°	15	80%	47%	40%
Hip extension ROM: involved side				
≥30°	262	52%	30%	25%
<30°	28	69%	54%	38%
Hip extension ROM: uninvolved side				
≥30°	271	52%	31%	26%
<30°	19	82%	47%	41%
Knee flexion ROM: involved side				
≥135°	224	52%	30%	24%
<135°	66	69%	54%	37%
Knee flexion ROM: uninvolved side				
≥135°	272	53%	32%	26%
<135°	18	65%	35%	35%

(continued)

Table 2.
Continued^a

Clinical Variable	n	Gait Deviation	Walking Speed ≤ 4 ft/s	Gait Deviation and Walking Speed ≤ 4 ft/s
Ankle DF ROM: involved side				
$\geq 20^\circ$	93	39%	22%	18%
$< 20^\circ$	197	60%	37%	30%
Ankle DF ROM: uninvolved side				
$\geq 20^\circ$	222	52%	30%	25%
$< 20^\circ$	68	58%	37%	31%
Ankle PF ROM: involved side				
$\geq 50^\circ$	135	39%	18%	16%
$< 50^\circ$	155	66%	44%	35%
Ankle PF ROM: uninvolved side				
$\geq 50^\circ$	264	52%	31%	26%
$< 50^\circ$	26	65%	38%	31%
Hip flexion strength				
≥ 4	221	51%	31%	24%
< 4	12	82%	64%	54%
Hip extension strength				
≥ 4	197	49%	28%	21%
> 4	36	70%	56%	47%
Hip abduction strength				
≥ 4	219	50%	31%	24%
< 4	14	92%	54%	46%
Knee flexion strength				
≥ 4	191	48%	28%	20%
< 4	42	72%	55%	50%
Knee extension strength				
≥ 4	185	50%	27%	21%
< 4	48	62%	55%	42%
Ankle DF strength				
≥ 4	141	42%	23%	18%
< 4	92	68%	47%	36%
Ankle PF strength				
≥ 4	160	44%	23%	18%
< 4	73	69%	55%	41%

^aVAS=visual analog scale, ROM=range of motion, strength testing=0–5 scale, DF=dorsiflexion, PF=plantar flexion.

Hip extension strength also was found to correlate with gait pattern and speed. Although the knee flexors are involved mostly with energy absorption, the hip extensors are responsible for propulsion and forward acceleration of the trunk. In normal gait, propulsion is initiated after heel-strike and is maintained during mid-stance though eccentric activation of the hip extensor muscles.¹³ The hip extensors also lengthen the supporting limb and reduce excessive drop of the body's center of mass.¹⁴ Propulsion is an essential component of gait speed, while control of the stance limb allows for a smooth transition into the swing phase of gait. A study by Sadeghi et al²⁶ of patients with amputation showed that increased hip extensor strength and early activation during the stance phase is needed to control perturbations and normalize walking speed in order to compensate for the lack of ankle function on the amputated leg.

An unexpected finding was the strong contribution of decreased ankle PF ROM to gait deviation and walking speed of ≤ 4 ft/s. Other researchers^{50,51} have found ankle stiffness among patients with lower-extremity reconstruction and proposed that diminished ankle ROM contributes to impaired gait and stair-climbing ability, but a statistical association has not been reported in the literature.

The objective of our study was not only to identify factors significantly associated with gait deviation and decreased walking speed, but also to provide measurement guidelines that would assist clinicians with treatment planning and goal setting for patients with lower-limb reconstruction. The independent associations with gait deviation and impaired walking speed suggest that treatment plans of care should consider strategies to address the follow-

Table 3.

Bivariate Regressions of Clinical Variables by Gait Deviation and Walking Speed of ≤ 4 ft/s at 24 Months (n=277)^a

Clinical Variable	OR	95% CI	P
Mild pain	1.2	0.57–2.6	.61
Moderate-severe pain	2.2	0.97–5.0	.06
Nonreciprocal stair-climbing: ascend	3.4	1.9–6.1	<.001
Nonreciprocal stair-climbing: descend	3.2	1.8–5.7	<.001
<30 s unilateral stance: involved side	8.2	3.2–21.2	<.001
<30 s unilateral stance: uninvolved side	3.2	1.9–5.7	<.001
<10 s tandem standing balance	2.9	1.5–5.3	.001
<10 toe raises: involved side	7.1	2.9–17.1	<.001
<10 toe raises: uninvolved side	2.3	1.3–3.9	.004
1–2 cm thigh atrophy	1.1	0.60–2.0	.76
>3 cm thigh atrophy	1.5	0.74–3.2	.24
1–2 cm calf atrophy	0.63	0.32–1.3	.20
>3 cm calf atrophy	2.1	1.1–4.0	.02
<120° hip flexion ROM: involved side	2.8	1.2–6.6	.02
<120° hip flexion ROM: uninvolved side	1.9	0.65–5.5	.24
<30° hip extension ROM: involved side	1.8	0.79–4.2	.16
<30° hip extension ROM: uninvolved side	2.0	0.74–5.5	.17
<135° knee flexion ROM: involved side	1.8	1.0–3.4	.05
<135° knee flexion ROM: uninvolved side	1.5	0.55–4.3	.82
<20° ankle DF ROM: involved side	1.9	1.0–3.6	.04
<20° ankle DF ROM: uninvolved side	1.3	0.74–2.5	.33
<50° ankle PF ROM: involved side	2.7	1.5–4.9	.001
<50° ankle PF ROM: uninvolved side	1.2	0.52–3.0	.62
<4 hip flexion strength	3.8	1.1–13.1	.03
<4 hip extension strength	3.2	1.5–6.9	.002
<4 hip abduction strength	2.7	0.08–8.4	.08
<4 knee flexion strength	4.0	1.9–8.2	<.001
<4 knee extension strength	2.8	1.4–5.6	.003
<4 ankle DF strength	2.5	1.3–4.5	.003
<4 ankle PF strength	3.1	1.7–5.8	<.001

^aOR=odds ratio, CI=confidence interval, ROM=range of motion, strength testing=0–5 scale, DF=dorsiflexion, PF=plantar flexion.

ing impairments of the involved lower extremity: calf atrophy greater than 3 cm, hip flexion ROM below 120 degrees, ankle PF ROM below 50 degrees, ankle DF ROM below 20 degrees, and an MMT grade of less than 4 for hip and knee extension and flexion strength and ankle PF and DF strength. In addition, functional goal setting should consider: a reciprocal stair-climbing pattern, unilateral stance of the involved and uninvolved lower extremities for greater than 30 seconds, tandem standing balance for greater than 10 seconds, and the ability to perform more than 10 toe raises on the involved and uninvolved limbs.

Results from the multivariate analysis help inform treatment priorities, which appear to be improving ankle PF ROM to greater than 50 degrees, improving knee flexion strength to an MMT grade of greater than 4, and improving a patient's ability to ascend and descend stairs with a reciprocal stair-climbing pattern. Additionally, we believe that priority consideration should be given to improving hip extension strength and single-leg stance

of the involved and uninvolved limbs. Recommendations for future research include examining the predictive ability of these impairment and functional measures on impaired mobility and physical disability. Further investigation is needed to determine the timing of treatment strategies and to support the inclusion of ankle PF ROM, knee flexion and hip extension strengthening, stair climbing, and single-leg-stance balance training in goal setting for patients with lower-extremity reconstruction.

A number of limitations of our study must be acknowledged. Information on the primary outcome and the functional variables was available on 73% to 75% of the eligible subjects. Subjects who were lost to follow-up at 24 months were more likely to be of low socioeconomic status than those who completed the study. Thus, the results may be an underestimation of the sample's level of abnormal gait and the associative ability of the significant clinical predictors. However, data on strength and ROM were available for only 31% to 40% of our sample. Even though the missing data were accounted for in the analysis, the small amount of impairment data may have contributed to the insignificant findings of knee extension strength and ankle involvement. In

addition, the reliability of visual observations of gait deviation was not determined in this study and also should be considered in the interpretation of results.

The generalizability of our results is limited due to the focus of the study on patients from level I trauma centers. Limb-salvage outcomes may be influenced by the expertise of the staff from these level I sites. Moreover, the clinical variables were measured after 24 months, a period that may not be representative of full salvage recovery. Resolution of functional limitations and changes in gait may occur during the 24- to 36-month recovery period.

Conclusion

The most significant clinical factors associated with gait asymmetry and decreased walking speed among patients with lower-extremity reconstruction were ankle PF ROM of less than 50 degrees, an MMT grade of less than 4 for knee flexion and hip extension strength, a nonreciprocal stair-climbing pattern, and single-leg standing bal-

Table 4.

Multivariate Logistic Regression Model of Gait Deviation and Walking Speed of ≤ 4 ft/s at 24 Months (n=277)^a

Variable	OR	95% CI	P
Age (y)			
0-24 (ref)	1.0		
25-34	0.88	0.31-2.5	.81
35-44	1.3	0.47-3.7	.60
≥ 45	2.2	0.77-6.3	.14
Insurance			
None (ref)	1.0		
Commercial/Medicare	1.4	0.64-3.1	.41
Other	1.3	0.51-3.1	.62
Injury			
Dysvascular (ref)	1.0		
Foot/ankle/tibia	0.39	0.13-1.1	.08
Tibial fractures	0.89	0.36-2.2	.81
Ascend/descend stairs			
Reciprocal (ref)	1.0		
Nonreciprocal	2.7	1.4-5.3	.003
Unilateral stance: involved limb			
≥ 30 s (ref)	1.0		
< 30 s	3.1	1.0-9.7	.05
Unilateral stance: uninvolved limb			
≥ 30 s (ref)	1.0		
< 30 s	2.0	0.99-4.0	.05
Hip flexion strength			
≥ 4	1.0		
< 4	3.0	0.61-14.7	.18
Hip extension strength			
≥ 4	1.0		
< 4	2.3	0.89-6.0	.09
Knee flexion strength			
≥ 4	1.0		
< 4	2.8	1.1-6.7	.03
Ankle PF ROM: involved side			
$\geq 50^\circ$	1.0		
$< 50^\circ$	3.2	1.5-6.8	.002

^aModel includes all variables in table, as well as missing categories for balance, strength, range of motion, and stairs. CI=confidence interval, ref=reference, PF=plantar flexion, ROM=range of motion.

ance of the involved and uninvolved limbs of less than 30 seconds. These results can be used to inform treatment planning, to help prioritize clinical interventions, and for effective goal setting to attain unimpaired physical mobility among this patient population.

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