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Weight-Bearing Asymmetry During Sit-Stand Transitions Related to Impairment and Functional Mobility After Total Knee Arthroplasty

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Abstract

Objectives—To examine changes in weight-bearing (WB) asymmetry during sit-stand transitions for individuals during the first 6 months after unilateral total knee arthroplasty (TKA). Relationships between WB asymmetry, clinical measures of knee impairment, and functional mobility also were evaluated.

Design—Prospective repeated-measures design.

Setting—Clinical research laboratory.

Participants—People (N = 36) with knee osteoarthritis (OA) scheduled to undergo unilateral TKA and a control (CTL) group (N = 17 healthy people) were enrolled.

Intervention—The TKA group participated in acute, home, and outpatient phases of exercise-based rehabilitation.

Main Outcome Measures—WB asymmetry measured during a 5-Times Sit-to-Stand Test (FTSST) based on average vertical ground reaction force under each foot, self-reported knee pain using a numerical pain rating scale, knee active range of motion symmetry, knee extensor strength symmetry, FTSST time, 6-minute walk test distance, and Stair Climbing Test time.

Results—Compared with preoperative values, the TKA group showed greater WB asymmetry at 1 month after surgery ($P < .001$). By 6 months, the TKA group had less WB asymmetry than preoperative values ($P < .001$), which was not different from the CTL group. Symmetry in WB correlated with functional outcomes and symmetry of quadriceps strength for the TKA group 6 months postoperatively.

Conclusions—Patients with unilateral knee OA showed WB asymmetry during sit-stand transitions early after unilateral TKA that improved by 6 months after surgery and was no

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different from that for healthy people of similar age. For people in the first 6 months after TKA, greater symmetry was related to better function and strength symmetry.

Keywords

Arthroplasty; Knee; Physical function; Rehabilitation; Weight-bearing asymmetry

Functional limitations for patients after total knee arthroplasty (TKA) exist several years after surgery compared with healthy people of similar age.[1–5] For example, 60% of individuals in 1 study reported moderate to extreme difficulty descending stairs after TKA.[6] Moreover, the time required to ascend and descend a flight of 12 stairs was reported to be more than twice as long for individuals 6 months after TKA compared with healthy adults.[7] Identifying the factors related to such functional limitations is critical for developing targeted interventions to optimize rehabilitation outcomes.

Functional outcome measures correlated with asymmetry in weight-bearing (WB) for people with unilateral knee osteoarthritis (OA).[8] Additionally, there was an indication that improved WB symmetry during functional tasks after TKA had a role in improved performance of tasks, such as sit-stand transitions and walking.[9–11] It is possible that correlations between WB symmetry and functional task outcomes increase as the WB demands of the task increase. For example, Liikavainio et al[12] found greater WB asymmetry during stair climbing and descending than level walking tasks for people with asymptomatic knee OA.

In addition to functional limitations, WB symmetry was associated with muscle and joint impairments, such as quadriceps weakness,[9] pain,[13] and knee joint motion.[11] This implies that WB asymmetry not only could be linked to functional limitations after TKA, but also related to recovery of underlying muscle and joint impairments.

For people with unilateral TKA, WB asymmetry may be most problematic during early stages of rehabilitation. Although no study investigated the magnitude of WB asymmetry within the first month after TKA, there was an indication that WB symmetry improved significantly after 6 months of recovery relative to presurgical levels.[5,10] It is necessary to determine changes in WB symmetry during the course of recovery and the associations of WB symmetry with functional outcomes and impairments during the early stages of recovery after TKA.

There were 2 purposes for this study. The first was to document change in WB asymmetry in patients with unilateral TKA from before TKA to 6 months after surgery. Two hypotheses were associated with this purpose: (1) patients with unilateral TKA would show increased WB asymmetry 1 month after surgery compared with preoperative values and (2) 6 months after surgery, patients would show improved WB symmetry compared with preoperative levels, which would be no different from healthy persons of similar age. The second purpose was to identify associations between WB asymmetry and measures of functional mobility and impairment across the first 6 months after TKA. The hypothesis for the second purpose was that WB asymmetry would be negatively related to functional performance and impairment measures at all times (hypothesis 3).

METHODS

Participants

People with knee OA (N = 36; age, 63.4±7.6y [mean±SD]) scheduled to undergo unilateral TKA were enrolled in the study. Participants were recruited from the community in cooperation with local surgeons from October 2008 to September 2010. The intention was to examine patients with unilateral knee OA. To achieve this, volunteers were deemed ineligible if they reported more than half the level of pain on the nonaffected knee compared with the affected knee (based on a numerical pain rating scale [NPRS] of 0–10). Volunteers were excluded if they were not within the range of 50 to 85 years of age or had uncontrolled hypertension, uncontrolled diabetes, body mass index greater than 35-kg/m^2, neurologic impairment, or other unstable lower-extremity orthopedic problems.

Control (CTL) group participants were recruited through verbal and written announcement in the community from December 2008 to March 2009. WB asymmetry values during sit-stand transitions for the CTL group were reported previously.[8] Exclusion criteria to recruit a healthy, similarly aged CTL group were identical to the treatment group with the addition that healthy volunteers were excluded if they exercised fewer than 3 days a week (30min/d), had knee pain greater than 2 of 10 on an intermittent basis (based on an NPRS), or had knee pain with regular daily activity.

The Colorado Multiple Institutional Review Board approved the study, and written informed consent was obtained from all participants.

Intervention

At the time of acceptance to the study, all TKA group participants were scheduled to undergo TKA using a medial parapatellar approach, which occurred within 2 weeks after baseline testing. After surgery, participants underwent rehabilitation, including acute rehabilitation (2– 4d) followed by home and outpatient rehabilitation (8–14 visits). The length of postoperative rehabilitation was intentionally not controlled because this was an observational study designed to capture variability in outcomes. All treatment sessions were performed by a licensed physical therapist. The CTL group was tested at only 1 time and did not receive intervention.

WB Asymmetry

Measurement of WB for the lower limbs was made by using vertical ground reaction force (VGRF) data obtained from 2 force platforms (PS-2141[a]) 1 under each foot of each participant in both the TKA and CTL groups during performance of a 5-Times Sit-to-Stand Test (FTSST)[14] (see Functional Outcome Measures section for FTSST details). The sampling rate for the force data was 500Hz. VGRF was averaged across the 5 sit-stand transitions for the FTSST and normalized to body mass.

[a]**Suppliers**
PASCO Scientific, 10101 Foothills Blvd, Roseville, CA 95747.

A WB ratio (WBR)[8,10] was calculated by using the average VGRF data for each participant at each time. The WBR presented affected limb values divided by nonaffected limb values. A ratio equal to 1 represents perfect symmetry

$$\mathrm{WBR}=\mathrm{VGRF}_{\mathrm{A}}/\mathrm{VGRF}_{\mathrm{NA}}, \quad (1)$$

where $VGRF_A$ is the average VGRF under the affected limb and $VGRF_{NA}$ is the average VGRF under the nonaffected limb.

An absolute symmetry index (ASI)[15] was calculated by using average VGRF data at all times for the TKA and CTL group participants. The ASI indicated the absolute difference in VGRF between limbs, with a value of 0 indicating perfect symmetry

$$\mathrm{ASI}=2 \times |(\mathrm{VGRF}_{\mathrm{L}}-\mathrm{VGRF}_{\mathrm{R}})/(\mathrm{VGRF}_{\mathrm{L}}+\mathrm{VGRF}_{\mathrm{R}})| \times 100\%, \quad (2)$$

where $VGRF_L$ is the average VGRF under the left limb and $VGRF_R$ is the same for the right limb.

The ASI allowed for comparison of the absolute difference in WB between limbs so that 6-month postoperative values for the TKA group could be compared with the CTL group, in which participants did not have an affected and nonaffected limb.[8]

Impairment Measures

Three impairment measures were used for the TKA group: self-reported knee pain, knee active range of motion (AROM) symmetry ratio, and knee extensor strength symmetry ratio. Knee pain was quantified by patients self-reporting the level of pain in the affected knee on an NPRS (0 = no pain, 10 = worst possible pain) directly after performing the FTSST.

Knee AROM was calculated as the total range of motion the participant could actively achieve, from maximal extension to maximal flexion. Knee motion was measured by using a manual goniometer (Manual Universal Goniometer[b]) with the participant positioned supine. In this position, the participant’s leg began in maximal extension at the knee. The proximal arm of the goniometer was positioned along the long axis of the thigh, and the distal arm, along the long axis of the leg. To measure extension, the participant’s heel was placed on a block and the participant was instructed to extend the knee as straight as possible. Flexion was measured while the participant actively flexed the knee with the assistance of gravity by bringing the heel toward the back of the thigh. The maximal degree reached without assistance from the tester was measured. Similar testing protocols for manual goniometric measures indicate high to very high reliability.[16,17] Total AROM was recorded for each limb as the sum of maximal extension and flexion values. A symmetry ratio was calculated identical to equation 1, with the exception of knee AROM replacing VGRF measures.

The final impairment measure, knee extensor strength, was calculated by using maximum isometric knee extension torque recorded with an electromechanical dynamometer.[c] For this

[b]Fabrication Enterprises Inc, PO Box 1500, White Plains, NY 10602.
[c]HUMAC NORM CSMi, 101 Tosca Dr, Stoughton, MA 02072.

test, participants were seated and stabilized with hips flexed at 85° and knees flexed to 60°. When in position, participants pressed against the dynamometer with maximal effort into knee extension, and peak torque was recorded. Two warm-up trials were performed before 3 test trials. The highest value from the 3 trials was used for analysis. The test was repeated on both lower limbs. A peak torque ratio was calculated by using the same equation as ratio for WBR (equation 1) with the exception of using knee extension torque values in place of VGRF values.

Functional Mobility Outcome Measures

Three standardized clinical measures were used to quantify function for the TKA group: the FTSST, 6-minute walk test (6MWT), and Stair Climbing Test (SCT). The FTSST quantified the performance of transitions between sitting and standing.[14] Participants sat on a standard-height chair (46cm) with their feet on the center of each force platform. Placement of the chair in relation to the force platforms was dictated by participant-selected comfortable knee flexion position. The outcome for the FTSST was time (measured by using a handheld stopwatch[d]) to perform 5 transitions between sitting and standing with the start and endpoints being the participant seated with his/her back touching the backrest of the chair. Participants were instructed to perform the transitions naturally, as fast and safely as possible. Participants practiced the movement before testing, then 2 trials were recorded. The faster of the 2 trials was used for analysis. Participants were encouraged to not use their hands for support during the test on either the armrests of the chair or their lower extremities. However, to promote natural movement, participants unable to perform the test without use of hands were allowed minimal use.

The second functional outcome, the SCT (also measured by using a handheld stopwatch), was used to assess ability to ascend, turn around, and descend a 12-step flight of stairs. The SCT is a reliable and valid measure for people with functional limitations, such as those with knee OA.[18,19] Two trials of the SCT were performed, with the fastest time used for analysis. There was a handrail on the staircase, which participants were encouraged to not use during the test. However, participants unable to perform the test without use of the handrail were allowed minimal use to enable test completion.

Finally, the 6MWT is a common clinical measure of walking endurance.[20] This test was performed in a 30.5-m (100-ft) walkway, with patients instructed to walk back and forth to cover the greatest possible distance during the 6 minutes. Participants were allowed rest periods if needed without stopping the timer. The distance walked was recorded, and only 1 trial of the 6MWT was performed to minimize fatigue.

Statistical Analysis

The sample size estimate was based on WBR mean ± SD values for the first 10 participants. Using a 1-sample 2-tailed *t* test, a sample size of 32 was determined to achieve 80% power to detect a 10% difference between preoperative and 6-month postoperative times (α = .05). Based on this estimate and accounting for an expected drop out of less than 10% from

[d]Seiko, 1111 MacArthur Blvd, Mahwah, NJ 07430.

previous study experience involving patients after TKA (unpublished data, Stevens-Lapsley et al. June 2006-Oct 2008), a conservative estimate of 36 participants in the TKA group was derived.

Baseline comparisons of group demographics and anthropometrics were made by using independent *t* tests (for continuously scored variables) and chi-square test (for sex distribution). Differences in WBRs across times (preoperative, 1, 3, 6 months postoperative) were tested by using a maximum likelihood repeated-measures model. Post hoc testing was performed using linear contrasts. Comparison of ASI for WB between the TKA (6 months postoperative) and CTL groups was made by using an unequal-variance independent-samples *t* test. Associations of WBR with physical function and impairment measures were assessed by using Pearson product-moment correlation coefficients. α level was set at $P < .05$ for repeated-measures analysis and between-group comparisons. Confidence intervals (CIs) were calculated to interpret Pearson product-moment correlation coefficients.

RESULTS

Group Comparison

Data for demographics and anthropometrics of the TKA and CTL groups are listed in table 1. There were no significant differences between groups in sex distribution, age, or height. The TKA group weighed significantly more than the CTL group ($P = .032$). All outcome measure data for the TKA group at all times are included in table 2.

WB Asymmetry

There was a significant difference across time in WBRs ($P < .001$) in the TKA group. One month after TKA, WBR decreased (indicating greater asymmetry) by .19 (95% CI, .14 –.25; $P < .001$; see table 2). From 1 month to 3 months after TKA, the WBR increased by .20 and recovered to preoperative levels (95% CI, −.05 to .05; $P = .88$). At 6 months, the TKA group showed significantly better WB symmetry compared with preoperative values ($P < .001$). Figure 1 shows WBR values across all times for the TKA group.

By 6 months after surgery, there was a trend for the ASI in the TKA group (12.50±9.63) to be greater than in the CTL group (8.98±6.88); however, this was not significant ($P = .15$). Percentages of participants with lower average VGRF values in the affected limb compared with the nonaffected limb were 86% preoperatively and 100% at 1 month, 89% at 3 months, and 67% at 6 months postoperatively.

Correlations of WBR With Clinical Measures

The only impairment measure that consistently correlated with WBR was quadriceps strength ratio, which was related positively at each postoperative time (table 3). Thus, greater symmetry in WB during sit-stand transitions was associated with greater symmetry in quadriceps strength. In terms of functional outcomes, positive correlations with WBR were fair[21] (range, .26 –.39), with the exception of at 1-month for the 6MWT, for which there was no relation (see table 3). Greater symmetry in WB during sit-stand transitions was associated with improved function.

DISCUSSION

During the times tested, WB asymmetry during sit-stand transitions after unilateral TKA was greatest at 1 month after surgery and returned to preoperative levels by 3 months. By 6 months, WB was more symmetrical than preoperative levels. Additionally, an index of absolute side-to-side differences in WB was not statistically different for people 6 months after TKA compared with healthy people of similar age. These findings support our hypotheses and agree with previous reports indicating that WB asymmetry typically is resolved by 6 months after surgery.[10]

In general, greater WB asymmetry was associated with poorer functional mobility outcomes at all times. These functional correlations did not change appreciably across the first 6 months, with the exception of the relation between 6MWT and WBR, which showed no association 1 month after surgery. At 6 months, when WBR indicated typical symmetry, relationships of WB symmetry with FTSST, 6MWT, and SCT results were still fair. This finding also supports our hypothesis and agrees with previous studies linking WB symmetry and physical function.[5,9,10,22–24]

Considering the functional implications of WB asymmetry, it is encouraging that WB was more symmetrical at 6 months than preoperatively. However, WB asymmetry continued to be associated with functional performance, even after symmetry was restored to levels of healthy adults. Furthermore, it is possible that tasks requiring higher levels of lower-limb loading may show greater WB asymmetry at 6 months after surgery. For example, ascending and descending stairs creates a much greater demand for WB.[22,25] In the present study, SCT time had the highest correlations with sit-stand WBR of the 3 functional mobility measures, supporting the idea that WB asymmetry affects functional tasks with high levels of lower-limb loading.

Considering muscle impairments associated with recovery after TKA, it is possible that unloading of the affected limb with WB asymmetry early after surgery reduces the stimulus to the quadriceps muscle. Recovery of quadriceps strength after TKA is a critical component to functional improvement.[3,26–28] Additionally, people have less quadriceps strength in the affected limb several years after TKA compared with typical values for people of similar age, a possible reason for the prolonged functional deficits seen after surgery.[29,30] The data in this study support the notion that symmetry in WB may be linked to recovery of quadriceps strength symmetry because correlations between these values were associated positively at all times.

Interestingly, results indicate little or no association of WB asymmetry with knee motion symmetry and pain after TKA. Harato et al[11] found that a lack of surgical knee extension in standing was associated with WB asymmetry. In contrast, the lack of association between knee motion and WB asymmetry in the present study could be caused by differences in measurement. Harato[11] reported knee angle during relaxed standing rather than maximal extension angle, whereas the present study used full AROM. Additionally, the impact of knee extension range of motion on the FTSST score may be less than during standing.

In terms of pain symptoms, TKA leads to significant improvements for several years after surgery.[31] Although pain correlated fairly with WB asymmetry in people with unilateral knee OA before surgery,[8] there was no indication of a relationship after surgery at any time up to 6 months. This finding suggests that after surgery, factors other than pain, such as the quadriceps strength impairments mentioned, fear, or unresolved habitual movement patterns, may be associated most with WB asymmetry.[24]

Based on results of this study, it is reasonable to consider WB symmetry restoration as an important component to early rehabilitation after unilateral TKA. Targeting WB asymmetry early may attenuate prolonged deficits in functional performance and quadriceps weakness. Future research targeting WB symmetry restoration as an intervention is warranted.

Study Limitations

This study did not take into account joint angles during sit-stand transitions or quantify joint loading. For example, Su et al[32] showed that people after TKA tended to compensate with increased joint moments at the hip during rising from a chair compared with healthy individuals of similar age. It would be informative for future research to examine joint moment symmetries during sit-stand transitions related to functional performance and impairment measures over time. Also, our study examined WB symmetry during sit-stand transitions, a task with a relatively low-level of difficulty. Future research is warranted to examine WB symmetry during higher level tasks, such as stair ascent and descent. Finally, the lack of repeated WB ASI measurements for the CTL group did not allow assessment of typical variability across time. Future research should include CTL group measurements at each time to account for variability explained by factors related to testing time, such as learning effects.

CONCLUSIONS

Patients showed WB asymmetry during sit-stand transitions at 1 and 3 months after TKA, which improved by 6 months after surgery. Greater amounts of WB asymmetry correlated with poorer functional performance up to 6 months after TKA. WB asymmetry also was associated with quadriceps strength asymmetry through 6 months after surgery. As a whole, these findings suggest that WB asymmetry during tasks such as sit-stand transitions is an important impairment to consider when attempting to optimize rehabilitation and improve functional performance for people after TKA.

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List of Abbreviations

6MWT	6-minute walk test
AROM	active range of motion
ASI	absolute symmetry index
CI	confidence interval
CTL	control
FTSST	5-Times Sit-to-Stand Test
NPRS	numerical pain rating scale
OA	osteoarthritis
SCT	Stair Climbing Test
TKA	total knee arthroplasty
VGRF	vertical ground reaction force
WB	weight-bearing
WBR	weight-bearing ratio

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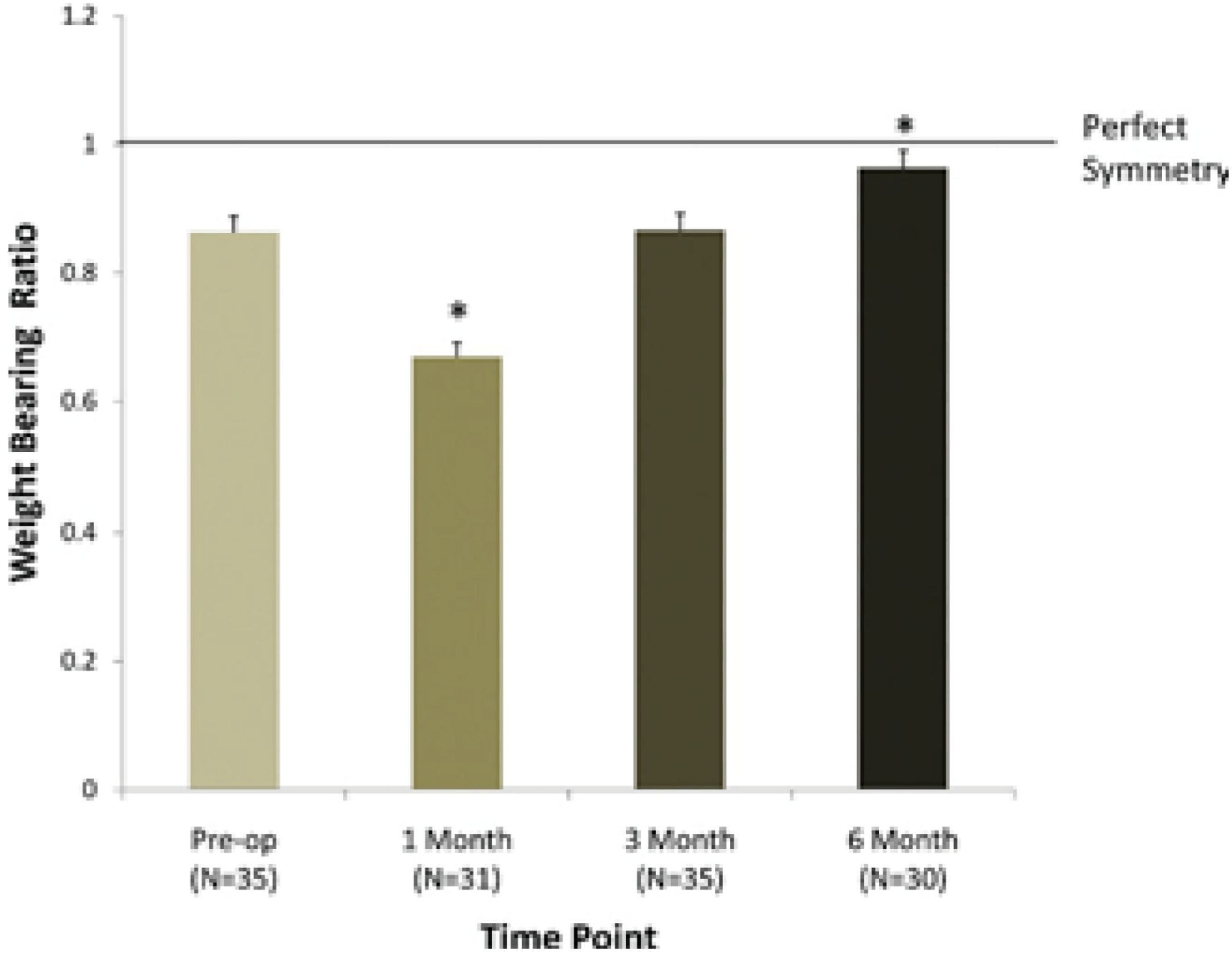

Fig 1.

WBR for average VGRF during transitions between sitting and standing. * Significant difference compared with preoperative (pre-op) measure ($P < .001$).

Table 1

Comparison of Baseline Demographics and Anthropometrics Between Groups

Characteristic	TKA	CTL	*P*
Sex	Women (n = 23)	Women (n = 8)	.240
	Men (n = 13)	Men (n = 9)	
Age (y)	63.4 ± 7.7	66.8 ± 6.5	.105
Body mass (kg)	91.0 ± 20.3	79.8 ± 15.4	.032
Body height (cm)	171.2 ± 9.9	170.6 ± 9.1	.811

NOTE. Values expressed as mean ± SD, except for sex, which is presented as number of women and men.

Table 2

WB Asymmetry, Impairment, and Functional Mobility Measures Before and After TKA

Variable	Preoperative	1 mo Postoperative	3 mo Postoperative	6 mo Postoperative
WB asymmetry measures				
WBR	0.86 ± 0.16	0.67 ± 0.16	0.87 ± 0.14	0.97 ± 0.16
ASI	19.5 ± 15.3	41.3 ± 24.3	18.1 ± 12.9	12.5 ± 9.6
Impairment measures				
NPRS	2.9 ± 2.8	3.5 ± 2.0	1.4 ± 1.9	0.6 ± 1.4
AROM ratio	0.90 ± 0.10	0.66 ± 0.11	0.82 ± 0.10	0.87 ± 0.09
Quadriceps strength ratio	0.78 ± 0.21	0.40 ± 0.14	0.76 ± 0.16	0.85 ± 0.17
Functional mobility measures				
FTSST (s)	13.9 ± 4.9	16.0 ± 4.9	12.6 ± 3.7	11.9 ± 4.1
6MWT (m)	459.0 ± 113.2	330.6 ± 115.3	465.3 ± 108.8	488.3 ± 80.8
SCT (s)	18.6 ± 10.3	32.9 ± 16.5	16.6 ± 7.7	14.3 ± 7.3

NOTE. Values expressed as mean ± SD.

Table 3

Pearson Product-Moment Correlations Between WBR and Outcome Measures Over Time

Variable	1mo *r* (95% CI)	3mo *r* (95% CI)	6mo *r* (95% CI)
NPRS	−.18 (−.50 to .18)	−.19 (−.49 to .14)	.07 (−.30 to .41)
AROM ratio	.29 (−.12 to .61)	.04 (−.34 to .41)	.23 (−.16 to .56)
Quadriceps strength ratio	.20 (−.16 to .52)	.46 (.15 to .69)	.40 (.03 to .66)
FTSST	−.33 (−.61 to .02)	−.26 (−.54 to .08)	−.31 (−.60 to .06)
6MWT	−.05 (−.32 to .40)	.35 (.01 to .61)	.38 (.01 to .66)
SCT	−.39 (−.65 to −.04)	−.37 (−.62 to −.04)	−.39 (−.65 to −.02)

Abbreviation: *r*, Pearson product-moment correlation.