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Early High-Intensity Rehabilitation Following Total Knee Arthroplasty Improves Outcomes

STUDY DESIGN: Prospective cohort study with an age-matched and sex-matched control group.

OBJECTIVES: To assess the clinical outcomes of a high-intensity rehabilitation program (HI) compared to those of a group of age-matched and sex-matched controls who underwent a lower intensity rehabilitation program.

BACKGROUND: Total knee arthroplasty (TKA) successfully alleviates pain from knee osteoarthritis; but deficits in function can persist long term. Despite these well-known deficits, there is little evidence supporting the use of rehabilitation interventions following TKA.

METHODS: Eight patients, who participated in the HI program, were compared to 8 age-matched and sex-matched patients who participated in a lower intensity rehabilitation program (control group). Patients were assessed preoperatively, and at 3.5, 6.5, 12, 26, and 52 weeks postoperatively. Assessment of patients included measures of pain, range of motion (ROM), functional performance, and quadriceps strength and activation.

RESULTS: There were no differences in knee ROM and pain between the HI and control groups at any postoperative time point. At the 3.5-week and 12-week (end of rehabilitation) time points, the HI group had better functional performance and quadriceps strength compared to the control group ($P<.05$). At the 52-week time point, the HI group continued to demonstrate better functional performance compared to the control group ($P<.05$), along with greater quadriceps strength ($P = .08$).

CONCLUSION: A HI program leads to better short- and long-term strength and functional performance outcomes compared to a lower intensity rehabilitation program. The HI program did not impair knee ROM and did not result in any musculoskeletal injuries in this small group of patients.

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More than 687 000 total knee arthroplasties (TKAs) are performed each year in the United States, secondary to the pain and physical limitations caused by knee osteoarthritis (OA).[11] Over the next 2 decades, the number of TKAs performed yearly is expected to grow dramatically to reach 3.48 million.[17]

Although TKA reliably reduces pain and improves self-reported function in patients with end-stage OA, the recovery of strength and function to normal levels is rare, which predisposes patients to future disability.[27,32,39] One month after TKA, quadriceps strength drops to 60% of preoperative levels, even when traditional postoperative rehabilitation is initiated within 48 hours after surgery.[23,35] This quadriceps weakness persists years after surgery, based on comparisons with age-matched controls.[13] Similarly, functional performance declines precipitously by up to 88% in the first month after TKA,[2] and reduced function persists, with reports of 18% slower walking speed and 51% slower stair-climbing speed compared to age-matched controls at 12 months after TKA.[39] Secondary to these strength and functional deficits, 75% of patients report difficulty negotiating stairs years after their TKA.[27] Moreover, 52% of patients after TKA report some limitation in performing functional activities, compared to only 22% of age-matched individuals without knee disorders.[27]

Despite these known impairments and activity limitations, there is little evidence to help guide rehabilitation of this population. In 2003, the National Institutes of Health concluded that "the use of rehabilitation services is one of the most understudied aspects of the perioperative management of patients following total knee replacement."[26] In 2007, the most recent meta-analysis on the effectiveness of physical therapy following TKA concluded that physical therapy has no long-term benefits.[20] However, these conclusions were based on only 5 studies that

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met the inclusion criteria for the meta-analysis. One potential reason for the lack of demonstrated efficacy of these trials is that none of the included trials examined the use of a high-intensity, long-duration rehabilitation program initiated immediately after discharge from the hospital. There is preliminary evidence that a progressive high-intensity rehabilitation program can lead to improved outcomes in this population, though this program was initiated 1 month after surgery, when strength and functional deficits were already profound.[29] However, there are concerns in the orthopaedic community that a higher intensity intervention initiated immediately following hospital discharge could lead to increased pain and swelling and ultimately to poorer range of motion (ROM) and functional outcomes.

The purpose of this study was to assess the clinical outcomes of a high-intensity, long-duration rehabilitation program after TKA, initiated after discharge from the hospital, compared to those of a lower intensity rehabilitation program in an age- and sex-matched control group.

METHODS

Study Design

This was a prospective, cohort study of patients who completed a high-intensity rehabilitation intervention (HI) after TKA, with comparison to an age- and sex-matched cohort of patients who completed a lower intensity exercise intervention (control group). Patients were assessed 1 to 2 weeks preoperatively, and 3.5, 6.5, 12, 26, and 52 weeks postoperatively. The 52-week assessment time was chosen for long-term follow-up, as patients recovering from TKA typically plateau in strength and functional gains by this time.[8,15,22] The study was approved by the Colorado Multiple Institutional Review Board. Informed consent was obtained from all participants, and the rights of participants were protected.

Participants

Eight patients (mean ± SD age, 65.3 ± 11.5 years; 5 females, 3 males) who underwent a primary unilateral TKA and completed HI were compared to an age-matched (±5 years) and sex-matched control group of patients who completed a lower intensity exercise intervention (mean ± SD age, 65.1 ± 11.5 years; 5 females, 3 males) as part of an ongoing clinical trial.[38] Patients participating in HI intervention were consecutively recruited from the community from February 2009 to November 2009. Patients who completed the lower intensity exercise intervention were control subjects in an ongoing clinical trial and recruited from the community from March 2007 to June 2010. The patients in both groups were included if they were between the ages of 50 and 85 years and were undergoing a primary unilateral TKA for end-stage knee OA. Patients in both groups were excluded if they had uncontrolled hypertension, uncontrolled diabetes, body mass index greater than 35 kg/m^2, significant neurologic impairments, significant contralateral knee OA (as defined by a verbal numerical pain rating of greater than 4/10 with walking or climbing stairs), or other unstable, lower extremity orthopaedic conditions.

TABLE 1 Preoperative Characteristics by Group*

Variable	HI Group	Control Group	*P* Value
Age, y	65.3 ± 11.5	65.1 ± 11.5	.98
BMI, kg/m^2	29.7 ± 4.6	30.9 ± 3.4	.58
Stair climbing test, s	17.0 ± 5.3	16.3 ± 8.6	.84
Timed up-and-go test, s	8.7 ± 1.5	9.0 ± 2.3	.71
6-minute walk test, m	441.0 ± 71.0	477.0 ± 117.0	.47
Knee flexion, deg	131.0 ± 6.0†	120.0 ± 10.0†	.02
Knee extension, deg	−0.9 ± 5.8	1.5 ± 1.8	.30
Quadriceps MVIC, surgical leg, Nm/kg	1.3 ± 0.5	1.2 ± 0.4	.72
Quadriceps activation, surgical leg, %	77.0 ± 15.3	70.1 ± 23.7	.50
NPRS‡ resting	2.5 ± 2.9	2.4 ± 1.8	.96
NPRS with quadriceps MVIC	1.1 ± 2.5	1.9 ± 2.4	.54
NPRS during stair-climbing test	2.9 ± 2.5	3.8 ± 2.7	.51

Abbreviations: BMI, body mass index; HI, high-intensity rehabilitation group; MVIC, maximal voluntary isometric contraction; NPRS, numeric pain rating scale.
**Values are mean ± SD unless otherwise specified*
†Difference between groups (P<.05).
‡The NPRS ranges from 0 to 10, with 0 as no pain and 10 the worst pain imaginable.

Interventions

Average length of stay in the hospital for both groups was 3 days, and patients were treated twice daily by staff physical therapists at their respective hospitals. Both groups began their assigned interventions upon discharge from the hospital. Both intervention groups had the following common elements in their rehabilitation programs: passive knee ROM exercises; patellofemoral joint mobilization (as needed); incision mobility; cycling for range of motion; lower extremity flexibility exercises for the quadriceps, calf, and hamstrings; modalities (ice or heat as needed); gait training; and functional training for transfers and stair climbing. All patients were given a home exercise program (HEP) to be performed twice daily during the acute phase of recovery (first 30 days) and then daily until discharge from therapy. For both intervention groups, the HEP included ROM exercises, and weight-bearing and non–weight-bearing strengthening exercises for the quadriceps, hamstrings, hip abductors, hip extensors, and plantar flexors. The intensity and types of exercises performed for the HEP were similar to those performed during the supervised

home and outpatient physical therapy sessions. However, patients in the HI group did not perform machine-based resistive strengthening as a part of their HEP.

Control Intervention Following discharge from the hospital, patients were treated in the home setting for 6 visits over 2 weeks, after which they were treated in outpatient physical therapy for an average of 10 visits over 6 weeks. Therefore, the total number of physical therapy sessions (home and outpatient) for this group after discharge was 16 visits over 8 weeks. All home health and outpatient physical therapists followed a standardized rehabilitation protocol, as previously described.[21] Both weight-bearing and non–weight-bearing exercises were initiated with 2 sets of 10 repetitions, then progressed to 3 sets of 10 repetitions. For strengthening exercises, weights were increased to maintain a 10-repetition maximum targeted intensity level; however, the maximum weight utilized for any strengthening exercise was a 4.5-kg (10 lb) ankle weight. Resistive exercises consisted of quadriceps setting, seated knee extensions, straight leg raises, sidelying hip abduction, and standing hamstring curls. Body weight exercises consisted of step-ups, side step-ups, step-downs (5- to 15-cm step), terminal knee extensions, single-limb stance, and wall slides.

HI Intervention Following discharge from the hospital, patients were treated in the home setting for 3 visits in the first week, after which patients were treated in outpatient physical therapy for 2 or 3 times per week until the completion of postoperative week 12, for a total of 25 visits. Both weight-bearing and non–weight-bearing exercises were initiated with 2 sets of 8 to 10 repetitions, then progressed by increasing the resistance or difficulty of the task. Exercises were progressed, based on achievement of predetermined milestones in addition to patient tolerance of the treatment. The **APPENDIX** provides a description of exercises and criteria utilized for this group. All exercises were progressed as tolerated, except when the following occurred: subjective complaints of decreased walking endurance, soreness for 2 hours or greater following the previous session, a decrease in knee ROM by 5° or more, an increase in knee joint swelling of 2 cm or more, or an increase in resting verbal numeric pain rating of 2 points or more. If the patient had 2 or more of the above findings, treatment for the subsequent session was adjusted to decrease intensity level to allow for recovery. If the only finding was soreness lasting 2 to 24 hours, then treatment was held at a similar intensity for that treatment session but only for exercises targeting the sore muscle group(s). Resistive training was initiated with an adjustable ankle weight but progressed to machine-based strengthening once a patient was not achieving fatigue with the ankle weight. Eccentric resistive strengthening was initiated when the patient met criteria for progression from phase 3. Eccentric strengthening was performed utilizing a weight machine, with both lower extrem-

TABLE 2 Postoperative Outcome Measures by Group Over Time*

Time/Variable	HI Group	Control Group
3.5 wk postoperative		
Stair-climbing test, s	23.6 ± 5.8	39.6 ± 18.5
Timed up-and-go test, s	8.9 ± 2.0	13.6 ± 4.4
6-minute walk test, m	381.0 ± 73.0	302.0 ± 88.0
Knee flexion, deg	96.0 ± 9.0	91.0 ± 14.0
Knee extension, deg†	2.8 ± 7.1	8.8 ± 6.5
Quadriceps MVIC, surgical leg, Nm/kg	1.0 ± 0.3	0.6 ± 0.2
Quadriceps activation, surgical leg, %	86.9 ± 6.2	73.1 ± 21.1
NPRS resting	1.1 ± 2.1	2.3 ± 1.4
NPRS with quadriceps MVIC	1.4 ± 2.2	2.0 ± 1.9
NPRS during stair-climbing test	1.1 ± 2.0	1.3 ± 1.2
6.5 wk postoperative		
Stair-climbing test, s	15.0 ± 4.4	22.9 ± 10.4
Timed up-and-go test, s	8.0 ± 1.8	10.9 ± 3.9
6-minute walk test, m	439.0 ± 73.0	374.0 ± 97.0
Knee flexion, deg	105.0 ± 12.0	103.0 ± 16.0
Knee extension, deg†	1.4 ± 6.0	4.9 ± 4.4
Quadriceps MVIC, surgical leg, Nm/kg	1.1 ± 0.2	0.9 ± 0.2
Quadriceps activation, surgical leg, %	89.4 ± 4.0	82.3 ± 13.0
NPRS resting	1.1 ± 1.4	1.0 ± 0.8
NPRS with quadriceps MVIC	0.3 ± 0.8	0.8 ± 0.9
NPRS during stair-climbing test	1.0 ± 1.4	1.9 ± 1.8
12 wk postoperative		
Stair-climbing test, s	12.2 ± 3.1	17.7 ± 9.2
Timed up-and-go test, s	7.1 ± 1.4	9.1 ± 2.5
6-minute walk test, m	493.0 ± 93.0	447.0 ± 98.0
Knee flexion, deg	115.0 ± 12.0	112.0 ± 11.0
Knee extension, deg†	0.1 ± 5.1	1.6 ± 2.4
Quadriceps MVIC, surgical leg, Nm/kg	1.4 ± 0.4	1.0 ± 0.3
Quadriceps activation, surgical leg, %	91.7 ± 5.9	81.0 ± 12.2
NPRS resting	0.4 ± 0.7	0.1 ± 0.4
NPRS with quadriceps MVIC	0.4 ± 0.8	0.3 ± 0.8
NPRS during stair-climbing test	0.8 ± 1.2	0.5 ± 1.1

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TABLE 2 Postoperative Outcome Measures by Group Over Time* (continued)

Time/Variable	HI Group	Control Group
26 wk postoperative		
Stair-climbing test, s	11.1 ± 2.9	15.1 ± 8.1
Timed up-and-go test, s	6.6 ± 1.1	9.1 ± 2.4
6-minute walk test, m	532.0 ± 73.0	457.0 ± 82.0
Knee flexion, deg	120.0 ± 12.0	114.0 ± 8.0
Knee extension, deg†	−1.9 ± 4.6	1.4 ± 3.0
Quadriceps MVIC, surgical leg, Nm/kg	1.7 ± 0.3	1.2 ± 0.3
Quadriceps activation, surgical leg, %	90.7 ± 6.7	79.3 ± 10.6
NPRS resting	0.4 ± 1.1	0.3 ± 0.7
NPRS with quadriceps MVIC	0.4 ± 1.1	0.0 ± 0.0
NPRS during stair-climbing test	1.3 ± 1.9	0.4 ± 1.1
52 wk postoperative		
Stair-climbing test, s	10.4 ± 2.8	17.3 ± 14.2
Timed up-and-go test, s	6.5 ± 1.3	8.8 ± 4.0
6-minute walk test, m	552.0 ± 69.0	470.0 ± 110.0
Knee flexion, deg	122.0 ± 12.0	117.0 ± 6.0
Knee extension, deg†	−3.3 ± 4.4	−1.0 ± 5.2
Quadriceps MVIC, surgical leg, Nm/kg	1.7 ± 0.3	1.4 ± 0.4
Quadriceps activation, surgical leg, %	89.1 ± 8.3	79.7 ± 15.3
NPRS resting	0.0 ± 0.0	0.3 ± 0.8
NPRS with quadriceps MVIC	0.0 ± 0.0	0.3 ± 0.7
NPRS during stair-climbing test	0.4 ± 1.1	0.9 ± 2.1

Abbreviations: HI, high-intensity rehabilitation group; MVIC, maximal voluntary isometric contraction; NPRS, numeric pain rating scale.
**Values are raw, unadjusted mean ± SD.*
†Negative values represent hyperextension.
‡The NPRS ranges from 0 to 10, with 0 as no pain and 10 the worst pain imaginable.

ities used for the concentric phase of the exercise and the surgical lower extremity alone for the eccentric phase.

Outcomes

Pain Pain was measured utilizing an 11-point verbal numeric pain rating scale (NPRS), with 0 representing no pain and 10 represented the worst pain imaginable. Patients were asked for their NPRS prior to testing, during quadriceps maximal voluntary isometric contraction (MVIC) testing, and during the stair climbing test (SCT). These tasks were chosen because they are demanding tasks during which patients frequently report knee pain.

Range of Motion Active knee ROM was measured in the supine position using a long-arm goniometer.[28] For active knee extension, the heel was placed on a 10-cm block and the participant was instructed to actively extend the knee. For active knee flexion, the participant was instructed to actively flex the knee as far as possible, keeping the heel on the supporting surface. Throughout this manuscript, negative values of extension represent hyperextension.

Isometric Quadriceps Torque and Activation Testing MVIC quadriceps torque and quadriceps activation were tested as previously described.[21] A HUMAC NORM electromechanical dynamometer (CSMi, Stoughton, MA) was utilized to measure torque. Data were collected using a BiopacData Acquisition System (Biodex Medical Systems, Inc, Shirley, NY) and analyzed using AcqKnowledge software, Version 3.8.2 (Biodex Medical Systems). A Grass S48 stimulator with a Grass Model SIU8T stimulus isolation unit (Grass Instruments, West Warwick, RI) was utilized for testing voluntary muscle activation. Quadriceps MVIC torque was normalized to body weight for between-subject comparisons. A quadriceps activation value of 100% represents full voluntary quadriceps activation, with anything less than 100% representing decreased motor unit discharge rates or incomplete motor unit recruitment.[3-4,36]

Functional Performance Measures Measures of functional performance included the stair climbing test (SCT), timed up-and-go test (TUG), and 6-minute walk test (6MW). The SCT measures the total time to ascend, turn around, then descend a flight of stairs. Patients were tested on 1 of 2 staircases during the study due to a change in facilities. One patient from the control group was tested on a 10-step stair case with a 17.1-cm step height. The remainder of patients from both groups were tested on a 12-step stair case with a 17.1-cm step height. The absolute times of the control patients with 10-step data were adjusted by a factor of 1.2 to allow for comparison between groups. The minimally detectable change associated with the 90% confidence interval (MDC_{90}) for this measure has been estimated to be between 2.6 and 5.5 seconds in patients recovering from TKA, depending on the time point assessed.[1,16] The TUG measures the time to rise from an arm chair, walk 3 m, turn around, and return to sitting in the same chair without physical assistance.[30] The MDC_{90} for the TUG in patients the first 1.5 months after TKA is 2.49 seconds.[16] The 6MW measures the total distance walked by an individual over 6 minutes. The MDC_{90} for the 6MW test is 61.34 m in patients the first 1.5 months after TKA.[16]

Statistical Methods

Primary Outcome and Endpoint The difference in SCT time between groups at 12 weeks (end of intervention) was chosen as the primary outcome, because stair climbing is a demanding task that poses difficulty for more than 75% of patients

after TKA.[10] Secondary outcomes were pain, knee ROM, quadriceps strength and activation, 6MW distance, and TUG time. Secondary time points of interest were 3.5 and 52 weeks after TKA.

Sample Size Estimate Sample size estimates were performed using SAS Version 9.2 (SAS Institute Inc, Cary, NC) and data from a cohort comparison study comparing community-based rehabilitation to a higher intensity exercise intervention in patients 1 year after TKA.[29] We expected at least a similar magnitude of effect on the SCT 12 weeks after TKA for this study (mean ± SD, 2.62 ± 1.90 seconds). We estimated that a sample size of 8 patients per group would provide 80% power to detect a difference of 2.62 seconds between groups on the SCT, using a 2-tailed independent samples *t* test with an alpha level of .05.

Data Analysis SAS Version 9.2 was used for all statistical analyses. The alpha level was set to .05 for all statistical comparisons. The data for all patients on all outcomes at all time points, except for 2 patients in the HI group who were missing quadriceps activation data at the 6.5-week (n = 1), 26-week (n = 2), and 52-week (n = 2) time points, were complete. Missing data for the 2 HI group patients were due to the patients declining this test secondary to discomfort. Statistical analysis of baseline differences between groups was carried out using an independent-samples unequal variance *t* test.

Differences between groups in the primary outcome and all secondary outcomes at 3.5, 6.5, 12, 26, and 52 weeks after TKA were analyzed using restricted maximum likelihood estimation of a multivariate repeated-measures mixed-effects model using all available data.[18] All models were conditioned on the outcome at baseline to account for any baseline differences and to increase statistical precision. All models contained fixed effects for group, time, and a group-by-time interaction, as well as a random effect for paired subjects between groups. Post hoc testing was performed using linear contrasts of pairwise comparisons between groups if a significant group-by-time interaction was found or if a significant group main effect was found in the absence of an interaction. All values are reported as mean ± SD, unless otherwise stated.

RESULTS

Preoperatively, participants in both groups were similar on all variables except for active knee flexion ROM (**TABLE 1**), with the individuals in the HI group having 11° greater knee flexion (P = .02; 95% CI: 1.9, 20.1).

All patients in the HI group were able to progress to phase 4 of the program, except for 1 patient, who only progressed to phase 3 secondary to continued challenges with this phase and increased knee pain with attempts to advance beyond this phase. During rehabilitation of the HI group, no patient necessitated decreasing treatment intensity based on the criteria established for progression. No individual in either group experienced a musculoskeletal injury during rehabilitation.

Postoperatively, no group differences were found between groups for active knee flexion (P = .76; 95% CI: −12, 9.0) or extension (P = .24; 95% CI: −5, 1) ROM. Active knee flexion for the HI group was 122° ± 12° compared to 117° ± 6° for the control group at 52 weeks (**TABLE 2**). Active knee extension for the HI group was −3° ± 4° compared to −1° ± 5° for the control group at 52 weeks (negative values represent hyperextension). Similarly, no group differences were found between groups for resting pain (P = .51; 95% CI: −0.7, 0.4), pain during the SCT test (P = .96; 95% CI: −1.0, 0.9), or pain during quadriceps MVIC testing (P = .74; 95% CI: −0.8, 0.6) (**TABLE 2**).

Postoperatively, a significant group-by-time interaction was found for TUG (P = .02) and quadriceps strength (P = .02). No significant interactions were found for SCT (P = .22), 6MW (P = .71), or quadriceps activation (P = .43). A significant group main effect was found for SCT (P<.005; 95% CI: −14.2, −2.7) and 6MW (P<.001; 95% CI: 42, 146). There was no significant group main effect for quadriceps activation (P = .06; 95% CI: −0.3, 15.9). Post hoc testing was performed on quadriceps strength, TUG, SCT, and the 6MW tests. Values reported for the 3.5-, 12-, and 52-week time points below are adjusted for baseline performance and include a random effect for pair.

At 3.5 weeks after TKA, the HI group performed 16.4 seconds faster on the SCT (P = .02; 95% CI: 3.1, 29.6) (**FIGURE 1**), 4.3 seconds faster on the TUG (P = .006; 95% CI: 1.5, 7.1) (**FIGURE 2**), walked 104 m farther on the 6MW (P = .001; 95% CI: 44, 164) (**FIGURE 3**), and had 0.3 Nm/kg greater quadriceps strength (P = .01; 95% CI: 0.1, 0.6) compared to the control group.

At 12 weeks after TKA, the HI group performed 5.8 seconds faster on the SCT (P = .01; 95% CI: 1.3, 10.4), 1.9 seconds faster on the TUG (P = .04; 95% CI: 0.1, 3.8), and had 0.4 Nm/kg greater quadriceps strength (P = .01; 95% CI: 0.1, 0.8) compared to the control group. The HI group also walked further on the 6MW test (P = .06; 95% CI: −4, 146), although this difference did not quite reach statistical significance.

At 52 weeks after TKA, the HI group performed 7.3 seconds faster on the SCT (P = .04; 95% CI: 0.5, 14.1) and walked 107 m farther on the 6MW (P<.001; 95% CI: 55, 158) than controls. The HI group also had greater quadriceps strength (P = .08; 95% CI: 0.0, 0.6) compared to the control group, although this difference did not quite reach statistical significance. Differences between the 2 groups on the TUG were no longer significant (P = .12; 95% CI: −0.6, 5.1).

DISCUSSION

The purpose of this study was to assess the clinical outcomes of a high-intensity intervention compared to a lower intensity rehabilitation program. Results indicate that utilization of a high-intensity program initiated ear-

ly in the course of recovery after TKA led to superior strength and functional outcomes, without leading to increased pain or decreased knee ROM outcomes, in this small group of patients.

There were 2 key differences between the rehabilitation programs utilized for this study. Patients in the HI group had 25 visits over 12 weeks, whereas patients in the control group had 16 visits over 8 weeks. Thus, the 2 groups had similar treatment frequency in the first 2 months, but the HI group was treated for an additional month. The second primary difference between the 2 programs was the level of intensity chosen for resistive strength training and the difficulty of the functional exercises utilized. Patients in the HI group performed machine-based resistive strengthening of all major lower extremity muscle groups, whereas patients in the control group did not utilize resistive training beyond levels accomplished by the use of ankle weights or resistive bands. The HI group also performed more complex functional exercises, such as star excursion balance reaching, multidirectional lunging, and agility exercises, once more basic functional exercises were mastered.

Considering the 2 differences between the programs, it is likely that treatment intensity was the primary driver of the differences in outcomes between groups. This conclusion is based on the fact that large differences between the 2 groups were already apparent 3.5 weeks after TKA, when the total number of treatment sessions was the same for both groups. However, it is possible that the greater duration of treatment was a significant factor for between-group differences at 12 weeks and 52 weeks after TKA. More research is needed to determine a true dose-effect relationship.

Individuals with end-stage knee OA have quadriceps weakness prior to TKA.[2,5,9] Following surgery, quadriceps weakness becomes more profound and does not recover to the level of healthy adults.[2,5,9,32,39,40] Quadriceps weakness has potential to impact function greatly,

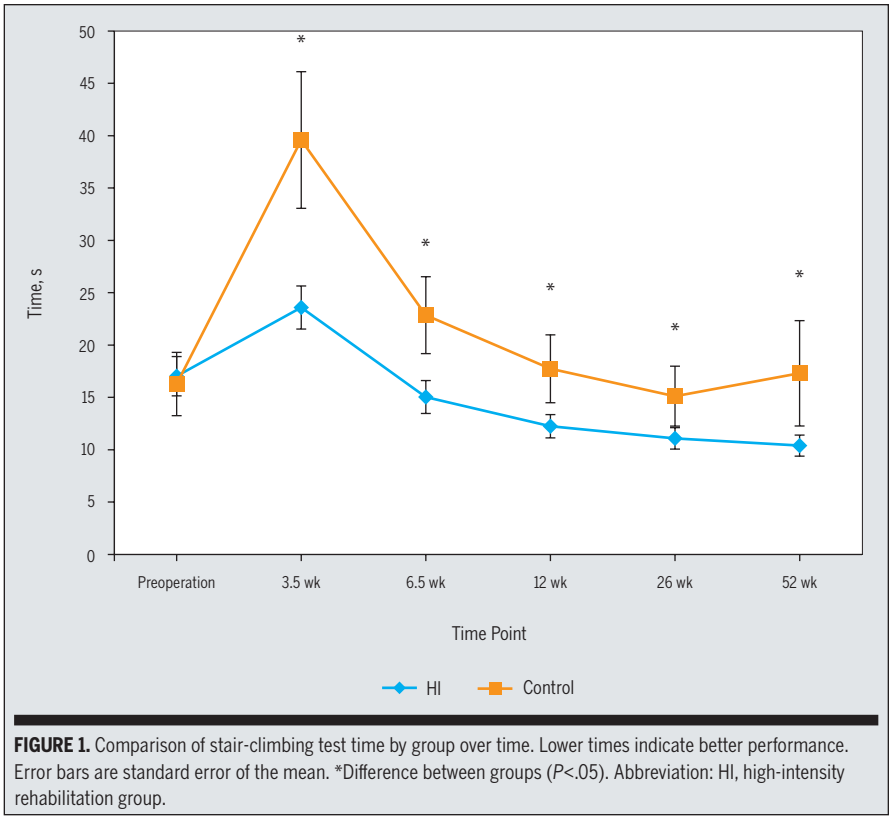

FIGURE 1. Comparison of stair-climbing test time by group over time. Lower times indicate better performance. Error bars are standard error of the mean. *Difference between groups (P<.05). Abbreviation: HI, high-intensity rehabilitation group.

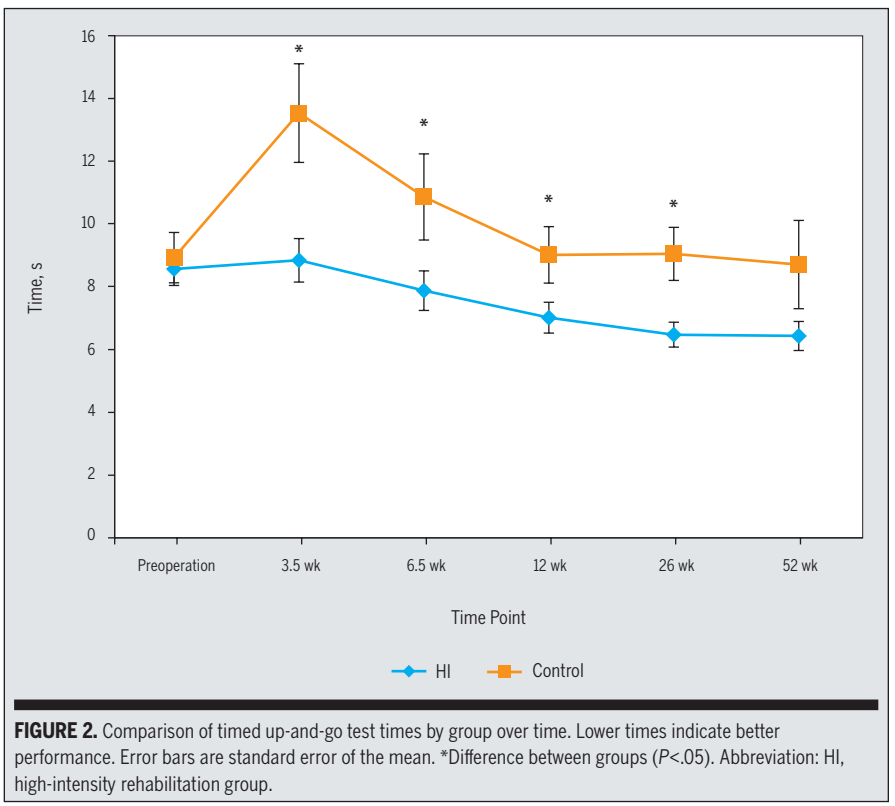

FIGURE 2. Comparison of timed up-and-go test times by group over time. Lower times indicate better performance. Error bars are standard error of the mean. *Difference between groups (P<.05). Abbreviation: HI, high-intensity rehabilitation group.

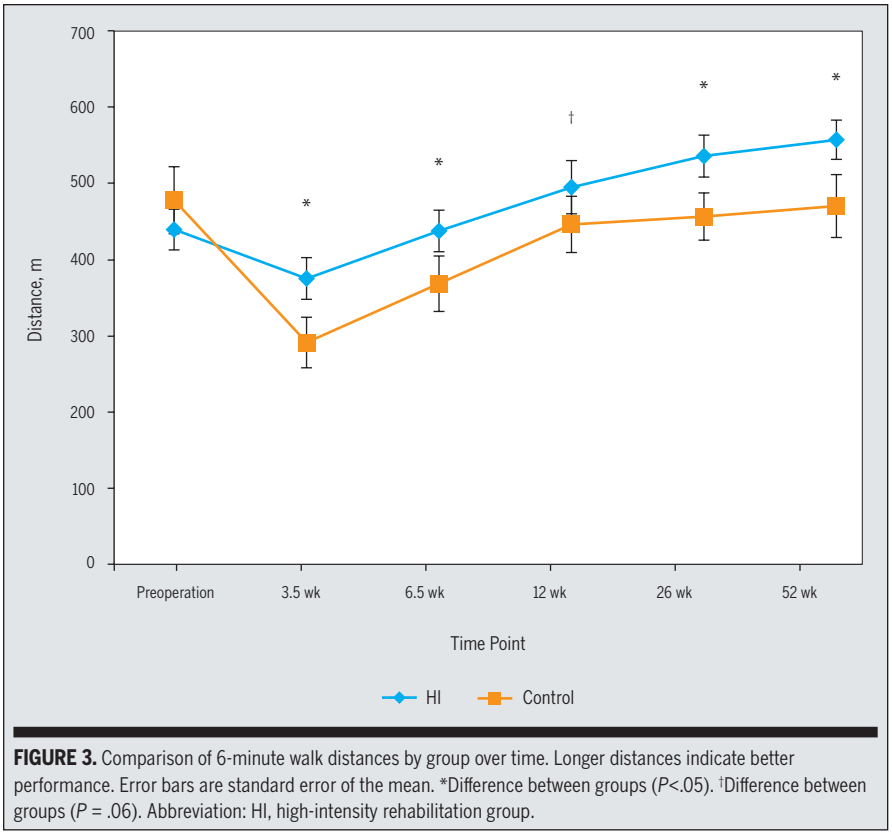

FIGURE 3. Comparison of 6-minute walk distances by group over time. Longer distances indicate better performance. Error bars are standard error of the mean. *Difference between groups (P<.05). †Difference between groups (P = .06). Abbreviation: HI, high-intensity rehabilitation group.

as quadriceps strength is related to stair-climbing ability, gait speed, chair rise ability, and risk for falling.[6,7,22,24,25,33] One month after TKA, quadriceps strength decreases by as much as 60%.[22] The mechanism for this profound, acute decrease is primarily explained by deficits in quadriceps voluntary activation rather than atrophy.[35] However, more than a year after TKA, quadriceps atrophy plays a more dominant role in the persistent strength losses observed.[19] It is probable that, during recovery from TKA, this period of decreased activation leads to the muscle atrophy and strength deficits observed in the long term. An intervention that targets quadriceps muscle activation deficits in the early postoperative period may be able to mitigate the long-term strength losses seen commonly in this population by preventing muscle atrophy. Preliminary evidence suggests that progressive resistive exercise is capable of reversing activation deficits.[12,14,31,37] However, no investigation to date has examined the ability of resistive exercise training to decrease activation deficits in the first month following TKA, when it is most profound. In this study, quadriceps strength was greater in the HI group compared to the control group at the 3.5- and 12-week time points. However, while quadriceps activation tended to be greater in the HI group compared to the control group (P = .06; 95% CI: −0.3, 15.9), the difference in quadriceps activation between groups was not statistically significant. Due to the small sample size of this study, clinically important differences in quadriceps activation could not be ruled out. A larger trial is needed to determine a more precise effect of the HI intervention on quadriceps activation.

Functional performance on the SCT, TUG, and 6MW are decreased prior to TKA in patients with end-stage knee OA compared to healthy adults. Following recovery from TKA utilizing traditional rehabilitation techniques, patients have 105% longer SCT times, 63% longer TUG times, and 28% shorter 6MW distances compared to healthy adults of similar age.[2] In this study, functional performance on the SCT and TUG was superior in the HI group compared to the control group at 3.5 and 12 weeks after TKA. Overall, the HI group had significantly better 6MW distances compared to the control group, with the exception of the 12-week time point, at which the difference was 71 m (P = .06; 95% CI: −4, 146). At 52 weeks after TKA, the HI group continued to demonstrate clinically superior outcomes on the SCT and 6MW tests. However, at 52 weeks, differences on the TUG were no longer statistically different. This is most likely due to a ceiling effect with the TUG, as mean performance of the HI group on this measure was 6.5 seconds at 52 weeks. Mean performance for the TUG in this age group has been reported to be between 5.6 and 8.0 seconds, which indicates that the HI group had recovered to normative levels on this measure at 52 weeks.[2,34] Mean performance on the SCT at 52 weeks for the HI group was 10.4 seconds. Average performance by healthy adults on the SCT is 8.9 ± 1.7 seconds, which indicates that the HI group recovered to within 1 standard deviation of normative performance by 52 weeks.[2] Mean performance on the 6MW test for the HI group was 552 m at 52 weeks. Average performance on the 6MW in this age group has been reported between 538 to 600 m, indicating that the HI group recovered to normative levels on this measure at 52 weeks.[2,34] This preliminary study suggests that the HI program is capable of remediating commonly observed activity limitations following TKA.

A recent meta-analysis by Minns Lowe et al,[20] which was based on the results of 5 articles, concluded that there were no long-term benefits of receiving physical therapy following TKA. Key differences between the HI program detailed in this cohort study and the articles examined in the meta-analysis are (1) the total number of physical therapy sessions and (2) intensity of treatment.

In the meta-analysis, the total number of physical therapy treatments ranged from none (home exercise program only) to 15, which is substantially lower than the 25 visits provided to the HI group. The intensity of exercise programs described was also far lower than that utilized for the HI intervention. None of the exercise programs in the meta-analysis utilized resistance beyond ankle weights or resistive bands. Additionally, none of the exercise programs in the meta-analysis utilized higher level functional exercises such as lunges. Based upon personal communication with therapists and orthopaedists, the reason for this focus on lower resistance, less intense programs is the belief or assumption that a more aggressive program will lead to increased pain and decreased ROM. However, these detrimental effects were not observed in the patients included in the HI group compared to the control group. Because individuals following TKA need to recover not only from the surgery itself but also from functional deficits present prior to surgery, it may be unrealistic to expect them to overcome these deficits with a brief and low-intensity intervention.

The primary limitations of this study are a lack of randomization, lack of blinding, and small sample size. A larger blinded, randomized controlled trial is needed to reduce potential bias and determine if the results observed in this cohort study are consistent in a larger population of patients. Additionally, patient compliance and activity levels were not tracked in this investigation. Differences in activity level, as well as patient compliance, might have affected the observed differences between groups.

CONCLUSION

The high-intensity rehabilitation program described in this cohort study demonstrated significantly greater short-term and long-term strength and functional performance increases compared to a lower intensity rehabilitation program. The high-intensity rehabilitation program was initiated immediately following hospital discharge and did not compromise knee ROM outcomes, cause musculoskeletal injury, or increase pain in this small group of patients. Key differences between the 2 programs were a greater number of treatment sessions over a longer period and the use of machine-based resistive strengthening and higher level functional exercises. ◉

KEY POINTS

FINDINGS: A high-intensity rehabilitation program, consisting of higher treatment intensity, longer treatment duration, use of single-leg machine-based resistive strengthening, and a higher level of progression of body weight exercises, led to superior strength and functional outcomes compared to a lower intensity rehabilitation program.

IMPLICATION: The implementation of more intense and long-duration interventions after TKA should be considered, as the results of this study suggest the potential for better functional short- and long-term outcomes.

CAUTION: A small sample size and lack of randomization and blinding may limit the strength of conclusions from this study.

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APPENDIX

High-Intensity Rehabilitation Program

Phase 1 (Weeks 0-2)
- Supine knee flexion (heel slides)
- Short-arc knee extensions
- Standing bilateral squats
- Sidelying hip external rotation, with hips flexed to 45° and knees flexed to 90° (clams)
- Sidelying hip adduction
- Supine ankle plantar flexion and dorsiflexion (ankle pumps)

Progression:
- When able to complete 2 × 8 repetitions without fatigue; NPRS at rest, <5/10; ROM, >15°-80°

Phase 2 (Weeks 0-4)
- Seated single-leg knee extension*
- Straight leg raise*
- Standing hamstring curls*
- Sidelying hip adduction*
- Sidelying hip abduction*
- Standing bilateral calf raises
- Repeated sit-to-stand transfers
- Marching or single-limb stance
- Multidirectional stepping

Progression:
- When able to complete 2 × 8 reps without fatigue; NPRS at rest, <5/10; ROM, >15°-90°

Phase 3 (Weeks 2-12)
- Seated single-leg knee extension*
- Seated single-leg knee flexion*
- Single-leg press*
- Single-leg calf press*
- Standing hip extension, flexion, abduction, and adduction*
- Step-ups, side step-ups, step-downs
- Forward lunging
- Single-limb stance progression (shoe to sock to foam, with eyes open, then with eyes closed)
- Tilt board squats
- Wall slides to 90° of knee flexion
- Stability ball supine hip extension

Progression:
- When able to complete 2 × 8 repetitions without fatigue; NPRS at rest, <3/10; ROM, >10°-100°

Phase 4 (Weeks 6-12)
- Seated single-leg knee extension (eccentric)*
- Seated single-leg knee flexion (eccentric)*
- Single-leg press (eccentric)*
- Single-leg calf press (eccentric)*
- Standing hip extension, flexion, abduction, and adduction*
- Step-ups, side step-ups, step-downs
- Multidirectional lunging
- Star excursion balance reaching
- Wall slides with 5- to 10-second endurance holds at 90°
- Stability ball supine combined hip extension with knee flexion
- Agility exercises: side-shuffle, backward walking, and braiding
- Single-limb stance progression

Abbreviations: ROM, total active arc of knee range of motion; NPRS, numeric pain rating scale.
*Resistive exercise utilizing ankle weight, resistive band, cable column or machine.