International Journal of Physical Medicine & Rehabilitation

Piva et al., Int J Phys Med Rehabil 2015, 3:6
DOI: 10.4172/2329-9096.1000311

Research Article Open Access

Dose-Associated Changes in Gait Parameters in Response to Exercise Programs after Total Knee Arthroplasty: Secondary Analysis of Two Randomized Studies

Sara R Piva[1*], **Shawn Farrokhi**[1], **Gustavo Almeida**[1], **Kelley Fitzgerald G**[1], **Timothy J Levison**[2] **and Anthony M DiGioia**[2]

[1]*Department of Physical Therapy, School of Health and Rehabilitation Sciences, University of Pittsburgh, USA*

[2]*Bone and Joint Center, Magee-Women's Hospital of the University of Pittsburgh Medical Center, USA*

[*]**Corresponding author:** Sara R Piva, Department of Physical Therapy, School of Health and Rehabilitation Sciences, University of Pittsburgh, USA, Tel: 412-383-6712; E-mail: spiva@pitt.edu

Received date: 29 August, 2015; **Accepted date:** 23 November, 2015; **Published date:** 28 November, 2015

Abstract

Background: Rehabilitation plays an important role to improve the outcomes of total knee arthroplasty (TKA). Evidence about the appropriate dose of exercise to recover gait dysfunction after TKA is limited. We posed the research question: In patients during the post-acute stage after TKA, is increased dose of exercise associated with larger improvements in gait parameters such as step length and single support time?

Methods: This was a secondary analysis from two randomized studies on exercise after TKA to investigate dose-dependence of gait parameters in response to exercise. Participants were 50 years or older who underwent unilateral TKA at least two months prior. They participated in 2 months of supervised exercises followed by 4 months of a home exercise program. The primary outcome was change in gait parameters from baseline to 6 months. Participants were divided in three groups according to the dose of exercise: group 1 (light-to-moderate intensity exercise), group 2 (high intensity + functional exercise), and group 3 (high intensity + functional + balance exercise). Jonckheere-Terpstra test was used to test if the magnitude of changes in gait parameters increased from group 1 to group 3 in an ordered fashion.

Results: Increased dose of exercise was associated with progressive increases in step length in the operated-limb ($p=0.008$) and decreases in step length in the non-operated limb ($p=0.011$). Increased dose of exercise was associated with ordinal decreases in loading response time ($p=0.049$) and increases in single-leg support time ($p=0.021$) on the operated- limb, but not on the non-operated-limb. Increased dose of exercise was associated with decreases in unloading time on the non-operated-limb ($p=0.011$) but not on the operated-limb ($p=0.400$).

Conclusions: Significant dose-response of exercise on gait parameters support the promotion of more intensive exercise programs that combine functional and balance training programs after TKA.

Keywords: Gait; Exercise; Rehabilitation; Gait parameters; Osteoarthritis

Introduction

Knee osteoarthritis (OA) is among the most disabling medical conditions in the world's ageing population [1-4]. However, there is no clear consensus on how knee OA should be effectively managed [5-9]. Given the lack of long-term treatment options, knee OA leads to total knee arthroplasty (TKA) as the last option to relieve pain and improve function. Estimates suggest that around 1.3 million TKA surgeries are performed annually around the world [10].

While TKA has shown to be a cost-effective treatment for alleviating pain and restoring physical function [11], some gait alterations such as decreased support time and shorter step length in the operated limb, are known to persist for months or years after the TKA surgery [12-20]. From a biomechanical point of view, these persistent gait alterations are important as they may lead to a shift in relative load bearing from the operated limb on to the non-operated limb, which may increase the rate of disease progression reported after TKA [16,20]. From a clinical standpoint, normal gait is crucial for daily activities and one of the main goals of patients and health care providers after TKA.

Rehabilitation plays an important role in functional recovery after TKA. However, effective rehabilitation approaches to improve gait alterations after TKA remain elusive. It has been suggested that high-intensity resistance training along with functional and balance exercises are effective to improve functioning after TKA [21-26]. Empirical observation of these studies indicates a dose-dependence between exercise and outcome. Yet, there is currently no evidence to help clinicians select the appropriate dose of exercise to improve gait after TKA. To that end, we conducted two randomized studies on exercise after TKA that tested different strategies of exercise that could be combined to investigate this dose-dependence. One study tested the effectiveness of a high-intensity exercise program that combines functional and balance exercises compared to usual care exercises on physical function [27]. The other study investigated whether a functional exercise program supplemented with balance exercises improve physical function compared to functional exercise only [22]. This article reports the results of post hoc analyses of these studies to

Citation: Piva SR, Farrokhi S, Almeida G, Fitzgerald KG, Levison TG, et al. (2015) Dose-Associated Changes in Gait Parameters in Response to Exercise Programs after Total Knee Arthroplasty: Secondary Analysis of Two Randomized Studies. Int J Phys Med Rehabil 3: 311. doi: 10.4172/2329-9096.1000311

answer the following question: In patients who are in the post-acute stage after TKA, is increased dose of exercise associated with larger improvements in gait parameters such as step length and single support time of the operated and non-operated limbs? We hypothesized that significant dose-associated changes would be identified for spatial and temporal gait parameters.

Materials and Methods

A complete description of the studies included in this analysis is detailed in the primary publications [22,27]. Only the methodological details related to the post hoc analysis are provided here. The two studies were prospective randomized clinical studies implemented in the rehabilitation clinic of the Department of Physical Therapy at the University of Pittsburgh. All subjects signed consent forms approved by the University of Pittsburgh Institutional Review Board. Sample size was not estimated for this study as it reports on post hoc analyses.

Subjects from both studies were recruited through letters sent to patients who had undergone a tri-compartmental cemented TKA performed by the same surgeon. After surgery, all participants received the same rehabilitation while in the hospital and outpatient physical therapy as needed prior to study participation. Participants who were interested in the study called the study coordinator who fully explained the study, obtained consent, and examined subjects for eligibility.

Inclusion criteria were age above 50 years and a unilateral TKA done 2 to 6 months prior to starting the study. Subjects were excluded if they reported 2 or more falls within the previous year, were unable to ambulate a distance of 30 meters without an assistive device, had an acute illness, and had a history of cardiovascular disease, uncontrolled hypertension, severe visual impairment, lower-extremity amputation, or progressive neurological disorder. For this study, subjects were also required to have participated in the assessment of gait parameters.

Subjects were tested at baseline and 6 months after randomization by testers who were masked to study assignment. During baseline the subjects completed demographics, pain, and physical function questionnaires, which were used to describe the sample. Pain intensity in the surgical knee was assessed using an 11-point numeric pain scale anchored on the left with the phrase "No pain" and on the right with the phrase "Worst imaginable pain" [28,29]. Physical function was assessed by Western Ontario and McMaster Universities (WOMAC) Osteoarthritis Index [30-32].

Gait parameters were the main outcome of this study and were tested at baseline and 6 months. Gait parameters were measured using a reliable and valid electronic walkway (GaitRite® v 3.8, CIR Systems Inc., New Jersey, USA) connected to a portable computer [33-36]. Subjects were asked to walk at a self-selected speed during 8 successive passes across the walkway while wearing shoes. They started and finished walking 1.5 meters in front of and beyond the edge of the walkway to avoid acceleration/deceleration. Data collected from the 8 trials were averaged. Gait parameters included step length and three temporal parameters corresponding to the three phases of stance: loading response, single-leg support, and unloading times. Step length was measured in centimeters whereas temporal parameters were measured in seconds. Since gait parameters are affected by gait velocity, the gait data were adjusted by gait velocity in order to account for potential changes in gait velocity from pre to post intervention. Thus, step length is reported as a percentage of the stride length (step length/stride length) and temporal parameters are reported in percentage of the gait cycle (e.g., loading response/gait cycle). Because this study investigates dose-response to exercise, the variable of interest is the change in gait parameters (6-month value minus baseline value).

Randomization was done after baseline assessment by a research assistant not involved with recruitment and was stratified by gender and age in random block sizes of two and four. A statistician not involved with study enrollment generated the randomization plan using a validated computer program. In both studies, subjects were randomly assigned to one of two treatment groups. In study 1, the groups were a) Light-to-moderate Intensity Exercise or b) High-Intensity + Functional + Balance Exercise. In study two, the groups were c) High-Intensity + Functional Exercise or d) High-Intensity + Functional + Balance Exercise. To test our hypothesis, groups 'b' and 'd' were combined as one group since the exercise programs were then defined in an orderly fashion according to increased dose of exercise. Group 'a' (light-to- moderate intensity exercise) was defined as Group 1, group 'c' (high-intensity + functional exercise) was defined as Group 2, and groups 'b' and 'd' were combined and defined as Group 3 (high-intensity + functional + balance exercise)(Figure 1). All participants completed 12 exercise sessions supervised by physical therapists spread over 2 months, followed by 4 months of a home exercise program, totaling 6 months of exercise. The exercises were done on both legs.

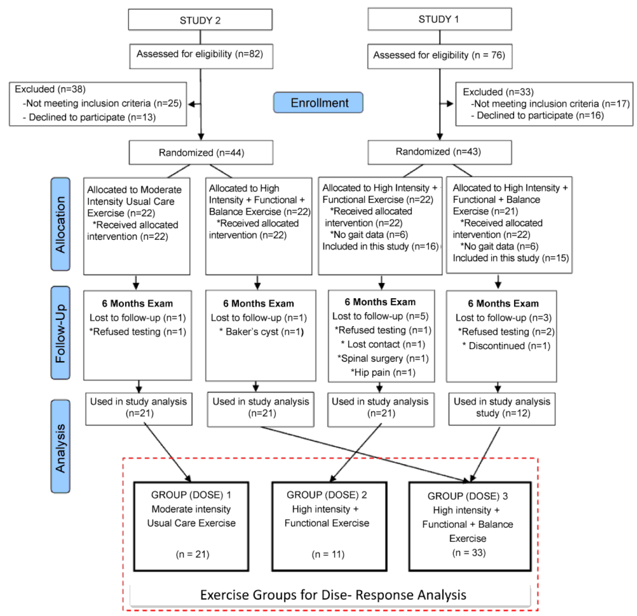


Figure 1: Flow Diagram of Two Studies used for this Post-hoc Analysis.

Group 1: light-to-moderate intensity exercise

This exercise program included warm-up, light-to-moderate intensity aerobic exercise, and resistance exercise. Warm-up consisted of 15 minutes of lower extremity stretching, range of motion, and stationary bike without resistance (Table 1). Aerobic training consisted of 20 minutes of light-intensity treadmill walking between 40-50% of age estimated maximal heart rate. Resistance exercise targeted knee extensors, knee flexors, hip extensors, and hip abductors (Table 1). Exercises used weight machines during supervised visits, whereas ankle weights and elastic bands were used for the home exercise program. The exercises using the weight machines were performed from light to moderate intensity, between 40-50% of 1 repetition maximum (1 RM). The level of effort using elastic bands and ankle weights as resistance was appraised by a perceived exertion scale with rates from light to moderate [37,38]. Subjects performed 2 sets of 20 repetitions of each exercise without reaching fatigue. Resistance exercise took around 40 minutes, totalling approximately 75 minutes of exercise for each session in this group.

Warm-up	Ankle range of motion-In long-sitting, ankle dorsal and plantarflexion.
	Knee range of motion-In long-sitting, flex the knee and hip as far as possible by sliding the foot toward the pelvis. Extension is done by sliding the foot back.
	Posterior leg stretching-In supine, with help of a belt, subject flexes exercise hip as far as possible keeping the knee in full extension (hold for 30 sec).
Resistance training	Knee extensors- Seated, long or short arc quadriceps. Exercise was performed from 90° to 60, from 30° to 0°, or terminal knee extension, depending on pain tolerance.
	Hamstrings curls in standing or lying prone (up to 60° of knee flexion).
	Hip abductors-side-lying with the back against a wall. Subject abducts the exercise hip ≈30°. The heel of the exercise limb touches the wall throughout the exercise. Ankle cuff weights are used for resistance.
Functional tasks	Get up and sit down from a chair. Initially use chair armrests for assistance and progress by not using armrest.
	Bilateral knee flexion/extension in standing. Start exercise bearing moderate body weight on handrail or counter, and progress not holding on handrail or counter. Exercise is also progressed into unilateral knee flexion/extension.
	Ascend and descend a flight of stairs. Progress speed as tolerated.
Balance/ dynamic stability	Side stepping. Progress by stepping over low obstacles.
	Braiding-alternate front and back cross-over steps while moving laterally (carioca).
	Tandem walk alternating legs with each step. Progress by stepping over low obstacles and by tandem walking backwards.
	Crossover walking-subject crosses one leg in front of the other, alternating legs with Each step to a maximum of ≈1ft width.
	Multiple change in direction-Therapist directs the subject to either walk forward, backward, sideways, or on diagonal by cueing patient with hand signals.
	Foam-subject stands on a soft foam surface with both feet on the ground. Therapist attempts to perturb patient balance in random fashion. Progress to single leg support.
	Tilt-board-subject stands on a tilt board with both feet on the board. The therapist perturbs the tilt board in forward and backward and side to side directions.

Table 1: Description of Exercises.

Group 2: high-intensity plus functional exercise

Subjects performed the same warm-up as described for Group 1, followed by high-intensity aerobic and resistance exercise, and functional task-oriented training. Aerobic training consisted of 20 minutes of treadmill walking between 50-75% of the age estimated maximal heart rate. The resistance exercise program was the same as in Group 1 but at a higher intensity. For weight machines, all exercises were performed at high intensity; between 60 - 80% of 1 RM. The level of effort using elastic bands and ankle weights as resistance was appraised by a perceived exertion scale with rates from moderate to vigorous. Subjects performed 2 sets of 8 repetitions of each exercise reaching fatigue [37,38]. Resistance exercises took around 20 minutes. Functional task-oriented exercises consisted of 10 minutes of bilateral and unilateral mini squats, chair rises, and stair climbing (Table 1). The exercise session took approximately 65 minutes.

Group 3: high-intensity plus functional exercise plus balance exercise

Subjects received the same program as described in Group 2, plus balance exercises that consisted of side stepping, tandem walking, cross-over steps during forward and backward walking, forward and backward walking to designated markers, multiple changes in direction, and standing over unstable surfaces (foam, tilt boards) (Table 1). These exercises took approximately 10 minutes, totaling around 75 minutes of exercise in this group.

Data Analysis

Differences in baseline characteristics across the groups were determined by Analysis of Variance (ANOVA) or Kruskal-Wallis, for continuous variables with normal or non-normal distribution respectively. Data normality was assessed by Shapiro-Wilk test. Chi square test was used for nominal variables. We also visually inspected these data for differences that could be clinically important but did not reach significance.

Citation: Piva SR, Farrokhi S, Almeida G, Fitzgerald KG, Levison TG, et al. (2015) Dose-Associated Changes in Gait Parameters in Response to Exercise Programs after Total Knee Arthroplasty: Secondary Analysis of Two Randomized Studies. Int J Phys Med Rehabil 3: 311. doi: 10.4172/2329-9096.1000311

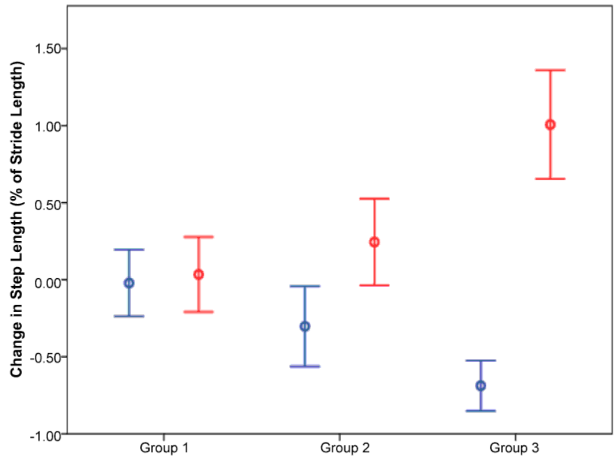
To test the hypothesis of significant dose-associated changes for spatial and temporal gait parameters, we first calculated the mean change for each gait parameter and then utilized the non-parametric test for ordered alternatives (Jonckheere-Terpstra for k samples). Johckheere-Terpstra test assesses the alternative that the magnitude of change in gait parameters increases from group 1 to group 3 in an ordered fashion. Jonckheere-Terpstra is the most appropriate and powerful test to use when samples are expected to have a natural ordering (i.e., the parameter of the first group is smaller than the second, which in turn is smaller than (i.e., the parameter of the first group is smaller than the second, which in turn is smaller than for ordinal trends of the 3 different dose groups. Statistical significance was defined as 2-tailed p<0.05. Analyses were performed using IBM SPSS v22.0 software (Armonk, NY).

Results

Details of recruitment and retention are available in Figure 1. Study one took place from Jan/2007 to May/2008 and study two from Oct/2011 to Aug/2013. Both studies stopped when target recruitment was reached. Of the 43 subjects enrolled in study one, 12 were excluded from analysis due to the lack of gait data because the gait mat was purchased after these first 12 subjects had been recruited. Additionally, 8 subjects in study one were not available during the 6-month follow-up and gait parameters could not be obtained. Of the 44 subjects enrolled in study two, two were not available during the 6-month follow-up. Subjects in the three intervention arms attended similar number of supervised exercise sessions, with an average of 11.5 out of 12 sessions (96%). There were no adverse events in both studies.

	Group 1 n=21	Group 2 n=11	Group 3 N=33	p-value
Age - Mean ± SD	69 ± 6.0	70 ± 9.5	67 ± 6.6	0.402
Gender-N of Female (%)	12 (57)	8 (73)	27 (82)	0.142
Race-N (%)				0.353
Caucasian	20 (95)	11 (100)	29 (88)	
African-American	1 (5)	0 (0)	4 (12)	
Marital Status-N (%)				0.934
Married	12 (57)	7 (64)	20 (60)	
Not Married	9 (43)	4 (36)	13 (40)	
Education-N (%)				0.489
Less than College Degree	9 (43)	4 (36)	9 (27)	
College Degree	12 (57)	7 (64)	24 (73)	
BMI (kg/m2) - Mean ± SD	30 ± 4.4	31 ± 4.0	30 ± 4.2	0.775
Months Since Surgery- Median (Range)	3 (2)	2 (3)	2 (3)	0.451
Number of surgeries on right side (%)	11 (52)	5 (46)	17 (52)	0.926
Number of Comorbidities‡- Median (Range)	2 (5)	2 (5)	2 (6)	0.589
Knee Pain¥ - Mean ± SD	2.2 ± 1.4	2.1 ± 1.2	2.9 ± 2.6	0.300
Physical Function†- Mean ± SD	18.4 ± 10.9	20.7 ± 8.5	19.1 ± 9.1	0.814

Table 2: Demographic and Biomedical Characteristics of Study Participants at Baseline. ‡ Number of Comorbidities was assessed as the number of health problems reported by the subjects including high blood pressure, stroke, diabetes, blood disorder, cancer, depression, back pain, memory problems, hip fracture, and lung, stomach, kidney, liver, or heart disease;¥ Knee pain was assessed by an 11-point numeric pain scale;† Physical function was assessed by the Western Ontario and McMaster (WOMAC) Universities Osteoarthritis Index; The WOMAC physical function subscore has 17 items (each scored from 0 to 4) with possible scores from 0 to 68 points. Larger scores in WOMAC indicate worse pain and function. WOMAC version LK3.1 was used.



	Group 1	Group 2	Group 3	P-value†
Δ in Step Length in OL	.03 ± .24	.25 ± .28	1.5 ± .35	0.008
Δin Step Lenght in NOL	-.02± .21	-.30± .26	-.69± .16	0.011

Markers and errror bars are means and standard errors. Values for the operated limbs (OL) are in red. Values for the non-operated limbs (NOL) are in blue.

Δ: Change score.

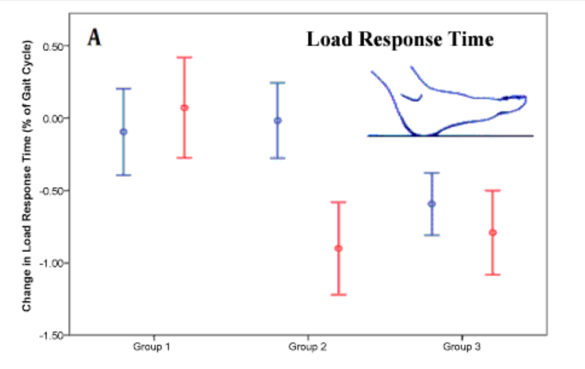
† P-values are for independent-samples Jonckheere-Terpstra test for ordered alternatives. It tests if the magnitude of change in gait parameters increases from group 1 to group 3 in an ordered fashion.

Figure 2: Changes in Step Length at 6 Months in the Three Exercise Dose Groups.

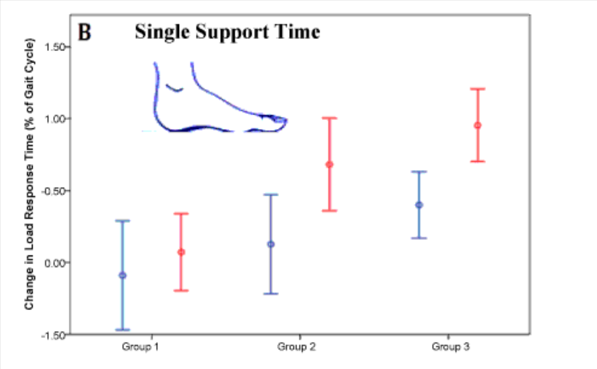
Both visual inspection and ANOVA results revealed no differences between the groups for demographic and biomedical characteristics (Table 2). Subjects in the three groups had low to moderate levels of pain and functional limitation.

Figure 2 represents the changes in step length for the three exercise groups along with results from Jonckheere-Terpstra tests. Significant dose-associated changes were identified for step length in the operated and non-operated limbs, but in opposite directions. Increased dose of exercise was associated with progressively larger increases in step length in the operated limb, whereas increased dose of exercise in the non-operated limb led to progressive larger decreases in step length.

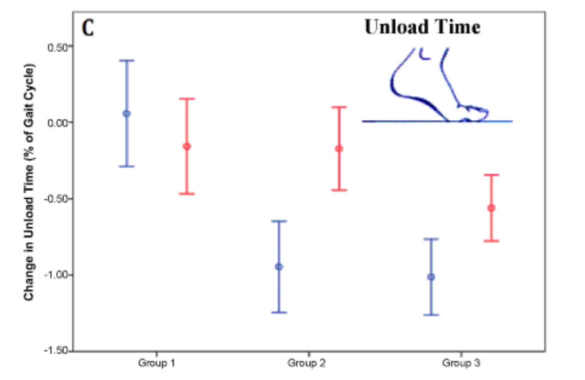
Figure 3 provides data for changes in loading response (Panel A), single-leg support (Panel B), and unloading (Panel C) times for the three exercise groups, along with results from Jonckheere-Terpstra tests. Significant dose-associated changes were identified for loading response, single-leg support, and unloading times. Increased dose of exercise was significantly associated with ordinal decreases in change in loading response time in the operated limb but not in the non-operated limb. Increased dose of exercise was also significantly associated with a progressive increase in change in single-leg support time in the operated limb. Although changes in single-leg support time in the non-operated limb was somewhat larger in group 3 as compared to group 2, which in turn was larger than group 1, the trend was not significant. Last, increased dose of exercise was significantly associated with progressive decreases in unloading time, but this trend was only significant in the non-operated limb.



	Group 1	Group 2	Group 3	P-value†
Δ in Load Response - OL	.07 ± .34	-.90 ± .32	-.79 ± .29	0.049
Δ in Load Response - NOL	-.09 ± .30	-.02 ± .26	-.59 ± .21	0.091



	Group 1	Group 2	Group 3	P-value†
Δ in Single Support - OL	.07 ± .27	-.68 ± .32	.95 ± .25	0.021
Δ in Single Support - NOL	-.09 ± .38	-.12 ± .34	.40 ± .23	0.400



	Group 1	Group 2	Group 3	P-value†
Δ in Unload - OL	-.15 ± .31	-.17 ± .27	-.56 ± .21	0.085
Δin Unload - NOL	.05 ± .34	-.94 ± .30	-1.0 ± .24	0.011

Markers and error bars are means and standard errors. Values for the operated limbs (OL) are in red. Values for the non-operated limbs (NOL) are in blue.

Δ stands for change.

† P-values are for independent-samples Jonckheere-Terpstra test for] ordered alternatives. It tests if the magnitude of change in gait parameters increases from group 1 to group 3 in an ordered fashion.

Figure 3: Changes in Load Response (Panel A), Single Support (Panel B) and Unload Times (Panel C) in the Three Exercise Dose Groups at 6 Months.

Discussion

To the best of our knowledge, this is the first study to investigate the dose-response of exercise programs on improvements in gait parameters in individuals after TKA. Our hypotheses of significant dose-associated changes for spatial and temporal gait parameters were affirmed. More specifically, ordinal increases in dose of exercise was associated with progressive increases in step length in the operated limb, and decreases in the non-operated limb; decreases in loading response time and increases in single-leg support time in the operated limb; and decreases in unloading time in the non-operated limb. Since gait alterations after TKA have been characterized by decreased support time and shorter step length in the operated limb, the findings of increased step length and single support time in the operated limb are positive ones and indicate beneficial effects of high exercise dose [12,14]. Thus, the findings provide credence to previous reports indicating that more intensive rehabilitation programs lead to clinically meaningful improvements in outcome during the later stages of recovery after TKA [21,22,24-26].

The longitudinal studies of pre and post TKA indicate that pre-surgery gait abnormalities are usually retained up to 18 months after surgery despite improvements in pain and range of motion [40]. As such, development or retention of gait alterations after TKA have been linked to the predictable patterns of further deterioration of the contralateral non-operated knee and the other lower limb joints [15,16]. If not treated appropriately, gait alterations observed after TKA, particularly those associated with joint loading, may contribute to the biomechanical factors that increase the rate of degeneration in the non-operated limb [16,41]. Even minor alteration in weight-bearing of the non-operated limb could have significant effects on disease status, as the average patient's walking activity after TKA approaches approximately 1-2 million gait cycles per year [42,43]. As such, considering the small alterations of the different components of the gait cycle may present a useful composite picture of repetitive or prolonged loading of the non-operated limb. The achievement of progressive faster load response and longer single support time in the operated limb with higher doses of exercise may be a prerequisite to decrease joint loading on the non-operated limb and prevent later disease or joint injury on the non-operated limb. To date, longitudinal studies have not examined the potential deleterious effects of gait alterations on the non-operated limb. Future longitudinal studies in the area of walking biomechanics and rehabilitation should pay particular attention to the non-operated limb after TKA.

Despite the widespread use of TKA, there is a notable lack of consensus regarding which rehabilitative post-operative practices should be employed in this patient population [10,24]. Given the significant clinical deficits in activities of daily living such as gait and stair climbing reported more than one year after TKA [44,45], intensive rehabilitation programs that include supervised training sessions have been recommended in the sub-acute recovery period after TKA to optimize functional ability and quality of life [21,22,24,26]. The feasibility of a more intensive rehabilitation program has been further substantiated with reports of high exercise adherence and satisfaction with low dropout rate and adverse events [21,22,27]. Therefore, the above evidence combined with the findings of the current study justifies the use of intense muscular strengthening, aerobic training, and functional training combined with balance exercises after TKA.

This study has limitations. Although this study supports a dose-response of exercise programs on improvements in gait parameters, the impact of these changes on knee joint kinematics or kinetics were not evaluated. Future work should consider evaluating the dose-response effects of exercise on the changes in the overall biomechanical characteristics of both operated and non-operated limbs. Moreover, the changes in spatiotemporal gait parameters from pre to post intervention, although significantly dependent on the dose of exercise, seemed rather small. The changes in gait parameters reported in the current study could not be directly compared to those of previous investigations as the raw values were either not reported or normalized differently [12,14]. Furthermore, cut-offs of clinical meaningful changes in gait parameters have not yet been established, which makes it difficult to adjudicate clinical significance. Last, while the participants in the study represent the usual population of individuals during the sub-acute phase of TKA recovery, results of this study only apply to people who have undergone a first uncomplicated total knee surgery for severe OA [21,46]. It is not clear whether the same results could be obtained after bilateral TKA, revisions, or in individuals with other concurrent lower limb problems.

Conclusion

The results of this study indicate that in patients in the post-acute stage after TKA, increased dose of exercise associate with larger improvements in gait parameters such as step length, loading response time, single-leg support time, and unloading time. The findings of significant dose-response of exercise combined with previous reports of better clinical outcomes after intense and comprehensive exercise programs justify promotion of more intensive exercise programs that combine functional training and balance programs after TKA. Further efforts are required to determine whether gait changes have an impact on the rate of further disease progression in the non-operated lower limb.

Source of Funding

This study was supported in part by Claude D. Pepper Older American Independence Center (P30- AG024827); the National Center for Medical Rehabilitation Research (NCMRR) (1 K01 HD 058035), and the Rehabilitation Institute Pilot Program - University of Pittsburgh Medical Center. The funding sources played no role in the investigation

References

1. Felson DT, Naimark A, Anderson J, Kazis L, Castelli W, et al. (1987) The prevalence of knee osteoarthritis in the elderly. The Framingham Osteoarthritis Study. Arthritis Rheum 30: 914-918.
2. Felson DT, Zhang Y, Hannan MT, Naimark A, Weissman BN, et al. (1995) The incidence and natural history of knee osteoarthritis in the elderly. The Framingham Osteoarthritis Study. Arthritis Rheum 38: 1500-1505.
3. Muraki S, Oka H, Akune T, Mabuchi A, En-yo Y, et al. (2009) Prevalence of radiographic knee osteoarthritis and its association with knee pain in the elderly of Japanese population-based cohorts: the ROAD study. Osteoarthritis Cartilage 17: 1137-1143.
4. Losina E, Weinstein AM, Reichmann WM, Burbine SA, Solomon DH, et al. (2013) Lifetime risk and age at diagnosis of symptomatic knee osteoarthritis in the US. Arthritis Care Res (Hoboken) 65: 703-711.
5. [No authors listed] (2000) Recommendations for the medical management of osteoarthritis of the hip and knee: 2000 update. American College of Rheumatology Subcommittee on Osteoarthritis Guidelines. Arthritis Rheum 43: 1905-1915.
6. Jordan KM, Arden NK, Doherty M, Bannwarth B, Bijlsma JW, et al. (2003) EULAR Recommendations 2003: an evidence based approach to the management of knee osteoarthritis: Report of a Task Force of the Standing Committee for International Clinical Studies Including Therapeutic Trials (ESCISIT). Ann Rheum Dis 62: 1145-1155.
7. Zhang W, Nuki G, Moskowitz RW, Abramson S, Altman RD, et al. (2010) OARSI recommendations for the management of hip and knee osteoarthritis: part III: Changes in evidence following systematic cumulative update of research published through January 2009. Osteoarthritis Cartilage 18: 476-499.
8. Skou ST, Roos EM, Laursen MB, Rathleff MS, Arendt-Nielsen L, et al. (2015) A Randomized, Controlled Trial of Total Knee Replacement. N Engl J Med 373: 1597-1606.
9. McAlindon TE, Bannuru RR, Sullivan MC, Arden NK, Berenbaum F, et al. (2014) OARSI guidelines for the non-surgical management of knee osteoarthritis. Osteoarthritis Cartilage 22: 363-388.
10. NIH Consensus Panel (2004) NIH Consensus Statement on total knee replacement December 8-10, 2003. J Bone Joint Surg Am 86-86A: 1328-35.
11. Kurtz SM, Ong KL, Lau E, Widmer M, Maravic M, et al. (2011) International survey of primary and revision total knee replacement. Int Orthop 35: 1783-1789.
12. Andriacchi TP, Galante JO, Fermier RW (1982) The influence of total knee-replacement design on walking and stair-climbing. J Bone Joint Surg Am 64: 1328-1335.

13. Chen PQ, Cheng CK, Shang HC, Wu JJ (1991) Gait analysis after total knee replacement for degenerative arthritis. J Formos Med Assoc 90: 160-166.
14. Lee TH, Tsuchida T, Kitahara H, Moriya H (1999) Gait analysis before and after unilateral total knee arthroplasty. Study using a linear regression model of normal controls-women without arthropathy. J Orthop Sci 4: 13-21.
15. Milner CE (2009) Is gait normal after total knee arthroplasty? Systematic review of the literature. J Orthop Sci 14: 114-120.
16. Shakoor N, Block JA, Shott S, Case JP (2002) Nonrandom evolution of end-stage osteoarthritis of the lower limbs. Arthritis Rheum 46: 3185-3189.
17. McClelland JA, Webster KE, Feller JA, Menz HB (2011) Knee kinematics during walking at different speeds in people who have undergone total knee replacement. Knee. 18: 151-5.
18. Farquhar SJ, Reisman DS, Snyder-Mackler L (2008) Persistence of altered movement patterns during a sit-to-stand task 1 year following unilateral total knee arthroplasty. Phys Ther 88: 567-579.
19. Lewek MD, Scholz J, Rudolph KS, Snyder-Mackler L (2006) Stride-to-stride variability of knee motion in patients with knee osteoarthritis. Gait Posture 23: 505-511.
20. McMahon M, Block JA (2003) The risk of contralateral total knee arthroplasty after knee replacement for osteoarthritis. J Rheumatol 30: 1822-1824.
21. Moffet H, Collet JP, Shapiro SH, Paradis G, Marquis F, et al. (2004) Effectiveness of intensive rehabilitation on functional ability and quality of life after first total knee arthroplasty: A single-blind randomized controlled trial. Arch Phys Med Rehabil 85: 546-556.
22. Piva SR, Gil AB, Almeida GJ, DiGioia AM 3rd, Levison TJ, et al. (2010) A balance exercise program appears to improve function for patients with total knee arthroplasty: a randomized clinical trial. Phys Ther 90: 880-894.
23. Villadsen A, Overgaard S, Holsgaard-Larsen A, Christensen R, Roos EM (2014) Postoperative effects of neuromuscular exercise prior to hip or knee arthroplasty: a randomised controlled trial. Ann Rheum Dis 73: 1130-1137.
24. Pozzi F, Snyder-Mackler L, Zeni J (2013) Physical exercise after knee arthroplasty: a systematic review of controlled trials. Eur J Phys Rehabil Med 49: 877-892.
25. Bruun-Olsen V, Heiberg KE, Wahl AK, Mengshoel AM (2013) The immediate and long-term effects of a walking-skill program compared to usual physiotherapy care in patients who have undergone total knee arthroplasty (TKA): a randomized controlled trial. Disabil Rehabil 35: 2008-2015.
26. Liao CD, Liou TH, Huang YY, Huang YC (2013) Effects of balance training on functional outcome after total knee replacement in patients with knee osteoarthritis: a randomized controlled trial. Clin Rehabil 27: 697-709.
27. Piva SR CM, Almeida GJ (2013) Comprehensive Behavioral Intervention Compared to Standard of Care Exercise Program after Total Knee Arthroplasty: A Pilot Randomized Trial. Arthritis Rheum 10: 356.
28. Jensen MP, Turner JA, Romano JM (1994) What is the maximum number of levels needed in pain intensity measurement? Pain 58: 387-392.
29. Katz J, Melzack R (1999) Measurement of pain. Surgical Clinics of North America 79: 231-252.
30. Bellamy N, Buchanan WW, CH G (1988) Validation study of WOMAC: a health status instrument for measuring clinically important patient relevant outcomes to antirheumatic drug therapy in patients with osteoarthritis of the hip or knee. Journal of Rheumatology 15: 1833-1840.
31. Bellamy N, Kean WF, Buchanan WW, Gerecz-Simon E, Campbell J (1992) Double blind randomized controlled trial of sodium meclofenamate (Meclomen) and diclofenac sodium (Voltaren): post validation reapplication of the WOMAC Osteoarthritis Index. J Rheumatol 19: 153-159.
32. Hawker G, Melfi C, Paul J, Green R, Bombardier C (1995) Comparison of a generic (SF-36) and a disease specific (WOMAC) (Western Ontario and McMaster Universities Osteoarthritis Index) instrument in the measurement of outcomes after knee replacement surgery. J Rheumatol 22: 1193-1196.
33. Menz HB, Tiedemann A, Kwan MM, Latt MD, Sherrington C, et al. (2003) Reliability of clinical tests of foot and ankle characteristics in older people. J Am Podiatr Med Assoc 93: 380-387.
34. van Uden CJ, Besser MP (2004) Test-retest reliability of temporal and spatial gait characteristics measured with an instrumented walkway system (GAITRite). BMC Musculoskelet Disord 5: 13.
35. Bilney B, Morris M, Webster K (2003) Concurrent related validity of the GAITRite walkway system for quantification of the spatial and temporal parameters of gait. Gait Posture 17: 68-74.
36. Webster KE, Wittwer JE, Feller JA (2005) Validity of the GAITRite walkway system for the measurement of averaged and individual step parameters of gait. Gait Posture 22: 317-321.
37. Day ML, McGuigan MR, Brice G, Foster C (2004) Monitoring exercise intensity during resistance training using the session RPE scale. Journal of strength and conditioning research / National Strength & Conditioning Association 18: 353-358.
38. Nelson ME, Rejeski WJ, Blair SN, Duncan PW, Judge JO, et al. (2007) Physical activity and public health in older adults: recommendation from the American College of Sports Medicine and the American Heart Association. MedSci Sports Exerc 39: 1435-1445.
39. Daniel WW (1990) Applied Nonparametric Statistics. 2nd edition ed. Pacific Grove, CA, USA.
40. Smith AJ, Lloyd DG, Wood DJ (2004) Pre-surgery knee joint loading patterns during walking predict the presence and severity of anterior knee pain after total knee arthroplasty. J Orthop Res 22: 260-266.
41. Milner CE (2008) Interlimb asymmetry during walking following unilateral total knee arthroplasty. Gait Posture 28: 69-73.
42. Schmalzried TP, Szuszczewicz ES, Northfield MR, Akizuki KH, Frankel RE, et al. (1998) Quantitative assessment of walking activity after total hip or knee replacement. J Bone Joint Surg Am 80: 54-59.
43. Silva M, Shepherd EF, Jackson WO, Dorey FJ, Schmalzried TP (2002) Average patient walking activity approaches 2 million cycles per year: pedometers under-record walking activity. J Arthroplasty 17: 693-697.
44. Roush SE (1985) Patient-perceived functional outcomes associated with elective hip and knee arthroplasties. Phys Ther 65: 1496-1500.
45. Walsh M, Woodhouse LJ, Thomas SG, Finch E (1998) Physical impairments and functional limitations: A comparison of individuals 1 year after total knee arthroplasty with control subjects. Physical Therapy 78: 248-258.
46. Petterson SC, Mizner RL, Stevens JE, Raisis L, Bodenstab A, et al. (2009) Improved function from progressive strengthening interventions after total knee arthroplasty: a randomized clinical trial with an imbedded prospective cohort. Arthritis Rheum 61: 174-183.