Managing Knee Osteoarthritis: The Effects of Body Weight Supported Physical Activity on Joint Pain, Function, and Thigh Muscle Strength

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Objective: To determine the effect of a 12-week lower body positive pressure (LBPP)-supported low-load treadmill walking program on knee joint pain, function, and thigh muscle strength in overweight patients with knee osteoarthritis (OA).

Design: Prospective, observational, repeated measures investigation.

Setting: Community-based, multidisciplinary sports medicine clinic.

Patients: Thirty-one patients aged between 55 and 75 years, with a body mass index ≥25 kg/m² and mild-to-moderate knee OA.

Intervention: Twelve-week LBPP-supported low-load treadmill walking regimen.

Main Outcome Measures: Acute knee joint pain (visual analog scale) during full weight bearing treadmill walking, chronic knee pain, and joint function [Knee Injury and Osteoarthritis Outcome Score (KOOS) questionnaire] during normal activities of daily living, and thigh muscle strength (isokinetic testing). Appropriate methods of statistical analysis were used to compare data from baseline and follow-up evaluation.

Results: Participants reported significant improvements in knee joint pain and function and demonstrated significant increases in thigh muscle strength about the degenerative knee. Participants also experienced significant reductions in acute knee pain during full weight bearing treadmill walking and required dramatically less LBPP support to walk pain free on the treadmill.

Conclusions: Data suggest that an LBPP-supported low-load exercise regimen can be used to significantly diminish knee pain, enhance joint function, and increase thigh muscle strength, while safely promoting pain-free walking exercise in overweight patients with knee OA. These findings have important implications for the development of nonoperative treatment strategies that can be used in the management of joint symptoms associated with progressive knee OA in at-risk patient populations.

Clinical Relevance: This research suggests that LBPP-supported low-load walking is a safe user-friendly mode of exercise that can be successfully used in the management of day-to-day joint symptoms associated with knee OA, helping to improve the physical health, quality of life, and social well-being of North America's aging population.

Key Words: knee OA, pain, function, strength, exercise, lower body positive pressure

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INTRODUCTION

Knee osteoarthritis (OA) is the most common form of arthritis,[1] with the World Health Organization (1997) reporting it as the fourth and eighth most common cause of disability in women and men, respectively.[2] Disease progression is commonly associated with gradual and debilitating joint pain and stiffness, which leads to an overall "de-conditioning" of the musculoskeletal system that manifests as (1) a loss of thigh muscle strength about the knee,[3] (2) diminished knee joint function,[4] and (3) increased body weight or body mass index (BMI).[5] Each of these changes make it difficult to perform essential activities of daily living such as walking, squatting, and going up and down stairs.[3]

Weight loss and regular exercise are both recommended for the management of symptoms associated with disease progression.[6,7] Although low-calorie dietary interventions may help reduce pain because of decreased joint loading during ambulation,[8] diet alone does not address factors such as thigh muscle weakness, loss of knee joint range of motion, and abnormal knee joint kinematics.[3–5] Research indicates that exercise can play an important role in the management of joint symptoms associated with disease progression.[9–13] Unfortunately, research to date has been unable to quantify the disease-modifying effect of any form of exercise,[9] and

there is currently the absence of data to support detailed exercise prescription based on a patient's stage of joint degeneration, level of impairment, comorbidities, activity preferences, or accessibility. As a result, exercise programs frequently lead to exacerbation of joint symptoms, have poor adherence and high drop-out rates, and involve activities (eg, weightlifting, stationary cycling, or aquatics) that the patient often perceives as having little impact on their ability to perform essential activities of daily living.

Recently, a new exercise treadmill (Figure 1) was developed, which permits low-load walking using an emerging technology called lower body positive pressure (LBPP).[14] The system uses a waist-high air chamber that can be inflated with positive air-pressure to accurately and consistently modify body weight during ambulation.[15–17] Lower body positive pressure is recognized as being superior to other methods of unloading (such as an upper-body harness or aquatic exercises) because the air pressure is applied uniformly over the lower body, thus reducing the formation of pressure points that are common with harness-based systems,[18,19] while maintaining normal muscle activation and gait patterns (which are altered during aquatic-based activities).[15,20,21] Lower body positive pressure exercise interventions have so far been reported on meniscectomy and anterior cruciate ligament reconstruction,[14] as well as lower limb trauma.[22] Each of these studies used LBPP to create a low-load exercise regimen that permitted patients to safely resume early and/or pain-free ambulation, or to walk further and for longer periods than were previously possible without exacerbation of symptoms. These reports suggest that LBPP may hold promise as a method of providing a safe and user-friendly form of remediated weight-bearing exercise for those with progressive knee OA or those at risk for developing or exacerbating knee OA symptoms due to obesity, or other conditions that preclude normal exercise activities.

The purpose of this study was to investigate the effect of a 12-week LBPP-supported low-load treadmill walking program on knee joint pain, function, and thigh muscle strength in overweight individuals with knee OA. The hypothesis was that participation in an LBPP-supported low-load walking program would significantly improve knee joint pain, function, and thigh muscle strength in overweight patients with knee OA.

METHODS

After ethics approval, 31 overweight patients with knee OA aged between 50 and 75 years were recruited to participate in a prospective, observation-based, repeated measures clinical investigation. Inclusion criteria were (1) body mass index ≥ 25 kg/m^2, (2) knee pain when performing normal activities of daily living (such as walking, squatting, or kneeling), (3) radiographic evidence of mild-to-moderate (Kellgren & Lawrence grades II or III) knee OA in 1 or both knees. Exclusion criteria included the following: (1) Kellgren & Lawrence grade III + radiographic evidence of severe knee OA, (2) history (within the last year) of traumatic hip, knee, or ankle injury or surgery, (3) use of crutches or a walking aid during ambulation, (4) history of medical conditions that would prevent physical activity, (5) history of cardiovascular disease, or screen positive for ankylosing spondylitis, psoriatic arthritis, chronic reactive arthritis, or renal problems requiring peritoneal dialysis or hemodialysis.

Participants were assigned an identification number and required to complete informed consent and knee demographic forms, which provided a detailed history of the participant's knee OA, such as history of injury or surgery, previous and current treatment methods such as bracing, injections, and pharmacological intervention. Knee OA severity was confirmed through antero-posterior radiographs, which were taken for all subjects in a weight-bearing position with both knees in 5 degrees of flexion.

Full weight bearing (FWB) baseline and follow-up evaluations were conducted immediately before and after participants' completion of a 12-week LBPP-supported low-load treadmill walking regimen. Evaluations were completed according to the previously described methodologies.[23] Briefly, testing consisted of the following: (1) anthropometric evaluation of height, weight, and thigh circumference, (2) evaluation of chronic knee joint pain and function using the Knee Injury and Osteoarthritis Outcome Score (KOOS) questionnaire, (3) isokinetic testing of thigh muscle strength, and (4) evaluation of acute knee joint pain during FWB treadmill walking using a 10-point visual analog scale (VAS).

After completion of the baseline evaluation, participants exercised for 25 minutes under low-load walking conditions twice weekly for 12 consecutive weeks on the G-Trainer treadmill at a set speed of 3.1 mph at 0-degree incline. For each low-load walking session, LBPP support was added in 5% increments each minute until one of the following criteria were met: (1) acute knee pain levels reached 0/10 on the VAS, (2) no further decreases in pain were achieved, (3) LBPP support reached a maximum of 40% body weight. Visual analog scale scoring of acute knee pain was collected at 5-minute interval over the duration of each low-load treadmill walking session, with the LBPP pressure being constantly monitored and adjusted in 1% increments to maintain a comfortable walking experience. The 5 VAS acute

FIGURE 1. Individual walking on G-Trainer treadmill by Alter G Inc.

knee pain scores and 5% of LBPP scores (taken at minute 5, 10, 15, 20, and 25) for each walking session were then averaged to obtain mean acute knee pain and LBPP support scores for each individual walking session. Participants were blinded to VAS scoring from previous walking sessions, as well as to the percentage of LBPP used to unweight them during each low-load walking session. The treadmill's LBPP blower and air chamber were on and pressurized even when participants were performing walking sessions with 0% LBPP support.

Paired t tests were used to compare baseline and follow-up scoring from anthropometric and isokinetic measurements. Nonparametric statistics were used for ordinal data, including KOOS scores, VAS acute knee pain scores, and percentage of LBPP support. Spearman correlation coefficients were calculated to examine the influence of factors such as age, BMI, and thigh strength on knee pain and function. Differences were considered statistically significant if $P \leq 0.05$.

RESULTS

Participants (22 female and 9 male) had a mean age of 64.2 years (SD = ±6.2; range, 53.0-75.0). Knee demographic data illustrated that all but 2 patients demonstrated radiographically confirmed knee OA bilaterally. For subjects with bilateral knee OA, the more symptomatic knee indicated by the subject was used as the "affected" side for evaluation.[24] On average, participants reported experiencing knee problems for 5.9 ± 4.7 years before the initiation of the study (ranging from 1 year to 20 years between subjects). Regarding previous treatment strategies, 72% of participants reported having physiotherapy, 42% used knee bracing, 32% had used anti-inflammatory medication, and 12% had previously received intra-articular injections for the management of symptoms. At the time of the study, no participants were receiving physiotherapy or intra-articular injections, but 2 participants were using prescription anti-inflammatory medications. Both participants chose to continue taking their medication consistently for the duration of their participation in the study.

Anthropometric data are presented in Table 1. Knee alignment evaluation through radiograph depicted that 19

subjects with varus alignment, 9 with valgus alignment, and 3 with normal alignment. A comparison of baseline and follow-up data revealed no significant changes in body weight, BMI, or waist circumference. A significant decrease was observed in the circumference measurements at knee joint line ($P = 0.023$) after the completion of the 12-week walking regimen.

Knee Injury and Osteoarthritis Outcome Score questionnaire scores at baseline and follow-up evaluation are presented in Table 2. Scores for each subscale can range from 0 to 100, with 0 indicating extreme knee problems and 100 indicating no knee problems. Since the Sport/Rec subscale evaluated activities that were not applicable to all participants (such as running, jumping, squatting, pivoting, and kneeling), an additional option of "Not Applicable" was provided. Each answer that was indicated as "Not Applicable" was treated as missing data, and in instances where more than 2 questions in a subscale had missing data, a subscale score was not calculated.[25] Twelve participants omitted more than 2 questions for the Sport/Rec subscale; therefore, only 19 subjects provided usable data for statistical analysis of that subscale. Significant improvements were found in all KOOS subscales after the completion of the 12-week low-load walking regimen, with the largest improvements for the entire group observed in the participant Quality of Life (QOL) subscale.

Isokinetic thigh muscle strength data expressed as a ratio of peak torque in newton meters to body weight in kilograms are presented in Table 3. Significant strength increases in both quadriceps and hamstring muscles were observed between baseline and follow-up testing at all 3 isokinetic testing speeds. Hamstring to quadriceps (H:Q) strength ratio data for baseline and follow-up testing sessions are also presented in Table 4. No significant differences in H:Q strength ratios were observed between testing sessions.

Visual analog scoring of acute knee pain during the baseline and follow-up FWB treadmill walking sessions are depicted for each participant in Figure 2. Data indicate that acute knee pain levels for the group (mean ± SD) significantly decreased ($P = 0.0001$) between baseline and follow-up evaluation, with 8 participants being able to walk pain-free during the follow-up FWB walking session. Unfortunately, 5 participants did experience an increase in acute knee pain during the follow-up FWB walking session.

The average percentage of LBPP required to minimize or eliminate acute knee pain during the first and last LBPP-supported low-load treadmill walking sessions performed

TABLE 1. Anthropometric Measurements—Mean ± SD (Range)

Anthropometry	Baseline	Follow-up
Weight (kg)	90.4 ± 17.2 (62.7-129.5)	89.7 ± 17.5 (61.8-128.7)
BMI (kg/m²)	32.8 ± 6.5 (25.7-51.4)	32.6 ± 6.6 (24.6-51.2)
Waist circumference (cm)	106.2 ± 13.1 (86.5-140.0)	106.5 ± 13.1 (81.5-136.5)
15 cm superior to KJL (cm)	51.6 ± 7.1 (41.0-70.0)	51.0 ± 6.9 (40.5-70.0)
8 cm superior to KJL (cm)	45.9 ± 6.1 (38.0-64.5)	45.5 ± 5.8 (37.0-63.5)
Knee joint line (cm)	40.6 ± 3.1 (37.0-49.0)	40.1 ± 2.7* (35.0-47.5)
15 cm inferior to KJL (cm)	38.3 ± 4.1 (30.0-50.0)	38.1 ± 3.5 (32.5-44.5)

*$P < 0.05$.
KJL, knee joint line.

TABLE 2. Knee Injury and Osteoarthritis Outcome Scores—Mean ± SD (Range)

Subscale	Baseline	Follow-up	*P*
Pain (n = 31)	54 ± 12 (33-78)	60 ± 15* (28-83)	0.02
Symptoms (n = 31)	55 ± 13 (32-89)	63 ± 17† (29-93)	0.001
ADL (n = 31)	58 ± 14 (34-87)	66 ± 16† (34-91)	0.007
Sport/Rec (n = 19)	27 ± 19 (0-60)	45 ± 24† (0-95)	0.003
QOL (n = 31)	32 ± 13 (6-50)	46 ± 14† (0-69)	0.0002

*$P < 0.05$.
†$P < 0.01$.
ADL, activities of daily living.

TABLE 3. Thigh Muscle Strength About the Affected Knee—Mean ± SD (Range)

	Baseline (n = 31)		
Knee	60 Degrees	180 Degrees	240 Degrees
Quadriceps	0.74 ± 0.35 (0.26-1.53)	0.45 ± 0.24 (0.06-0.96)	0.40 ± 0.24 (0.01-0.95)
Hamstrings	0.54 ± 0.22 (0.12-0.92)	0.38 ± 0.21 (0.09-0.77)	0.35 ± 0.22 (0.03-0.74)
	Follow-up (n = 31)		
Knee	60 Degrees	180 Degrees	240 Degrees
Quadriceps	0.86 ± 0.29* (0.42-1.41)	0.58 ± 0.19* (0.21-1.03)	0.50 ± 0.18* (0.13-0.90)
Hamstrings	0.65 ± 0.22* (0.12-1.04)	0.52 ± 0.18* (0.26-0.88)	0.48 ± 0.19* (0.12-0.86)

*$P < 0.01$.

during the 12-week exercise regimen are depicted in Table 5. Data suggest that at the end of the 12-week walking regimen, participants experienced significantly less knee pain while exercising and required significantly lower amounts of LBPP support to minimize their acute knee pain during exercise. Statistical analysis indicated that a strong positive correlation ($P < 0.001$; r = 0.82) existed between participants' VAS scoring and the percentage of LBPP support required to eliminate or minimize their acute knee pain during the final LBPP-supported low-load walking session.

DISCUSSION

To the best of our knowledge, this investigation is the first to examine the use of an emerging "un-weighting" technology called LBPP to support the implementation of a walking exercise regimen with knee OA patients. Our results suggest that LBPP support can be safely and successfully used to promote regular walking exercise without exacerbation of joint symptoms, and resulted in a significant decrease in knee joint pain, improved knee joint function, as well as a substantial increase in thigh muscle strength about the affected knee.

Patient demographics for the current investigation are similar to those previously reported in the knee OA literature.[26,27] The majority of participants were female, and representative of an aging, obese, and sedentary patient population who experienced significant pain and difficulties with normal activities of daily living. As such, these patients were at significant risk for exacerbation of joint symptoms after exercise.

TABLE 4. Hamstring to Quadriceps Strength Ratio—Mean ± SD (Range)

Angular Velocity (Degrees/s)	Baseline (n = 31)	Follow-up (n = 31)	P
60	0.70 ± 0.23 (0.40-1.30)	0.76 ± 0.16 (0.30-1.10)	0.763
180	0.94 ± 0.37 (0.20-1.80)	0.90 ± 0.20 (0.4-1.3)	0.627
240	1.08 ± 0.72 (0.10-4.0)	0.97 ± 0.26 (0.3-1.4)	0.422

No significant differences were found between baseline and follow-up H:Q strength ratios.

Anthropometric data illustrated that participants demonstrated a significant decrease in the circumference measurements at knee joint line ($P = 0.023$) after the completion of the 12-week walking regimen. Although this change may be indicative of diminished swelling about the affected joint, caution must be used when interpreting this result as the study methodology did not include any form of orthopedic evaluation to assess knee joint swelling as part of the baseline or follow-up evaluation protocol.

Data from the KOOS questionnaire suggest that study participants' chronic knee pain and joint function dramatically improved over the course of the investigation. Baseline scoring was below normal values previously reported in the literature.[28] On follow-up evaluation, KOOS values significantly improved and were more representative of normative values previously reported in the knee OA literature. This is an important finding because it suggests that our study participants experienced higher than normal levels of knee pain and dysfunction, and thus were representative of patients with OA at significant risk for exacerbation of joint symptoms after exercise. Beyond this, the significant change in KOOS scoring also serves to highlight the prominent role that low-load walking exercise can play in helping to promote safe, user-friendly weight-bearing exercise with even the most at-risk patient population. Anecdotally, many patients commented that they had not been able to participate in regular exercise for many years because of their knee pain or because of a lack of confidence associated with lower limb strength. Further analysis of the KOOS data to determine whether variables such as participant age, body weight (BMI), leg alignment, or thigh strength may have influenced baseline or follow-up KOOS scoring failed to reveal a significant correlation or trend to account for the lower than normal baseline KOOS scores, or the change in KOOS scoring.

Thigh muscle weakness is one of the earliest and most common features associated with disease progression.[29,30] Baseline evaluation of thigh muscle strength suggested that scoring was comparable with previously reports[24] and confirmed that the thigh muscle strength of our participants with knee OA was well below normal. Follow-up testing indicated that both hamstring and quadriceps muscle strength improved significantly at all testing speeds. Although research does suggest that targeted thigh muscle strengthening protocols can be used to improve muscle strength about an OA
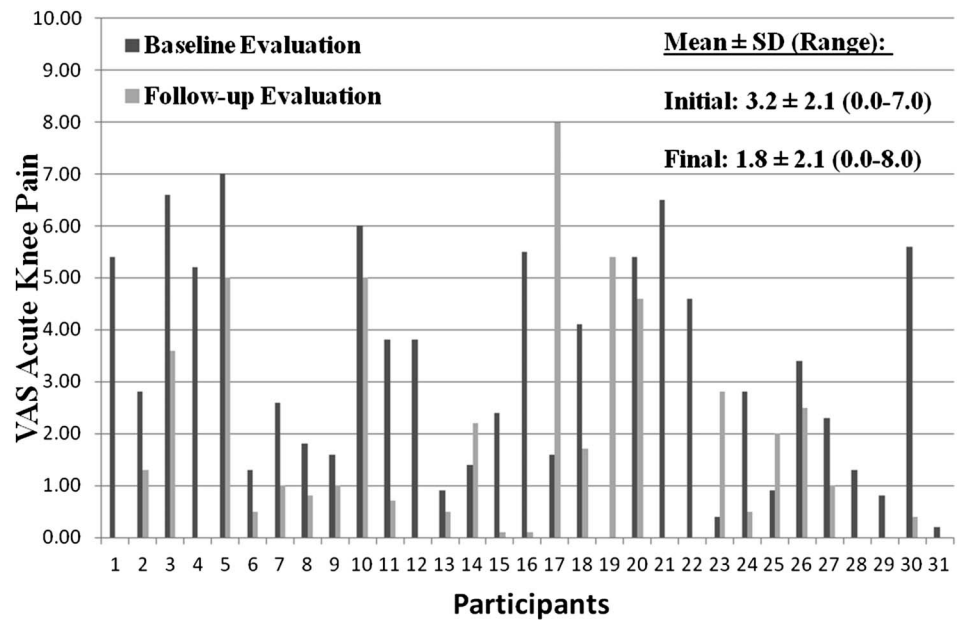
FIGURE 2. Acute knee pain during full weight bearing walking sessions mean VAS pain levels during initial and final FWB walking sessions for each participant.

knee,[10,31] there is limited evidence regarding the efficacy of aerobic activities (such as walking, cycling, or swimming) for enhancing thigh muscle strength in patients with knee OA.[32,33] Interestingly, the strength changes observed in the quadriceps and hamstring muscle groups were also found to be proportional (ie, hamstring to quadriceps strength ratio about the knee remained consistent when comparing baseline to follow-up results). This finding suggests that the reciprocal nature of muscle contraction observed during the low-load walking regimen facilitated a healthy balance in agonist/antagonist strength about the knee and may enhance functional capacity during regular activities of daily living.

Perhaps the findings of greatest clinical significance are those regarding participants' acute knee pain during FWB treadmill walking. Baseline testing revealed that participants experienced substantial acute knee pain during the initial FWB walking session. After completion of the 12-week walking regimen, acute knee pain during the follow-up FWB walking session was significantly reduced, with 7 of 31 (or 23%) participants able to walk pain free. Beyond this,

a comparison of VAS and LBPP data from the first and last LBPP-supported low-load walking sessions also suggested that participants required significantly less LBPP support to eliminate or minimize their acute knee pain during the final LBPP-supported low-load walking session.

Although these results may be indicative of the knee's ability to slowly accommodate to exercise, progressive joint loading, or the functional demands placed on it over the 12-week exercise regimen, it is also possible that gains made in thigh muscle strength over the course of the 12-week walking program may have served to attenuate forces being transmitted across the knee joint during walking exercise. Unfortunately, post hoc analysis comparing changes in acute knee pain with changes in thigh muscle strength failed to show a significant correlation. As such, caution should be used when interpreting the results, as 4 patients actually reported experiencing an increase in acute knee pain during their follow-up FWB walking session.

Finally, there are several limitations to this study. First, the methodological approach used in this investigation excluded direct examination of knee joint articular cartilage, or pathological biomarkers associated with articular cartilage health. As a result, no conclusions can be made regarding the disease-modifying effect of low-load walking exercise. Second, the within-subject repeated measures design of the investigation precluded the involvement of an adequate control group by which parameters associated with the natural progression of knee OA could be compared.[34] Third, concerns about how a patient's physical perception of LBPP support (ie, the air pressure) may confound VAS scoring of acute knee pain are valid (ie, a patient who perceives higher LBPP support may score their acute knee pain during walking lower on the VAS scale). Finally, the question of whether this type of exercise intervention is cost-effective, or superior to other methods of low impact, non–weight-bearing exercise warrants further

TABLE 5. Percentage of Unweighting and VAS Scoring From First and Last LBPP-Supported Low-Load Walking Session—Mean ± SD (Range)

LBPP-Supported Walking Sessions	First Session (n = 31)	Last Session (n = 31)	P
Acute knee pain (VAS score)	2.6 ± 1.8 (1.0-6.6)	1.8 ± 2.0* (0-8)	0.023
LBPP support (% of body unweighted)	17.9 ± 9.4 (3-35)	8.5 ± 8.3† (0-40)	0.002

*P < 0.01.
†P < 0.05.

investigation. Anecdotally, patients may prefer task-specific activities such as walking over other non–weight-bearing forms of exercise such as strength training, cycling, or aquatic exercise,[3,8,35] and there is currently no evidence to suggest that any 1 form of exercise is superior to another for the management of symptoms associated with knee OA.[2,36–38]

CONCLUSIONS

Our results suggest that LBPP-supported low load walking is a safe user-friendly mode of exercise that can be successfully used to diminish knee joint pain, enhance joint function, and increase thigh muscle strength in even the most at-risk overweight patient with knee OA. We believe that these results will assist in development of more effective evidence-based exercise strategies that can be used in the management of day-to-day joint symptoms associated with knee OA, and ultimately help to improve the physical health, QOL, and social well-being of North America's aging population. Further research is needed to determine the application limitations of this emerging technology, as well as to clarify how it could be used to study the long-term impact of regular exercise on knee OA pathogeneses and progression.

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