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High-Intensity Interval Training for Knee Osteoarthritis: A Pilot Study

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Objective. To assess the feasibility and changes in outcomes of a 12-week high-intensity interval training (HIIT) program in individuals with symptomatic knee osteoarthritis (OA).

Methods. The single-arm trial included 29 participants (mean ± SD age 63 ± 7 years; 66% women; 66% obese). Measures of participant flow, adherence, and tolerability were collected. Pain, function, and balance were assessed at baseline, 6 weeks, and 12 weeks using the Western Ontario and McMaster Universities Osteoarthritis Index, 20-m fast-paced walk test, 30-second chair-stand test, stair-climb test, timed up and go test, and single leg stance. Cardiorespiratory fitness, strength, and body composition were evaluated using peak oxygen consumption (VO_2peak), isometric knee extensor/flexor strength, and dual-energy x-ray absorptiometry, respectively. HIIT was completed two times/week (cycling or treadmill) and consisted of 10 repetitions of 1-minute bouts at 90% VO_2peak, with 1-minute rest periods. Separate multivariable-adjusted linear mixed models were fit for each outcome with fixed effects of time, age, sex, body mass index, and random effects of baseline values to estimate mean changes and 95% confidence intervals (CIs) between baseline and 12-week assessments.

Results. Recruitment aligned with the anticipated enrollment rate, adherence was 70%, and no adverse events were reported. At 12 weeks, improvements were observed for most outcomes, with notable mean changes for the 20-m fast-paced walk (–1.13 [95% CI –1.61 to –0.64] seconds), 30-second chair-stand (2.6 [1.8-3.4] stands), and VO_2peak (0.14 [0.03-0.24] liters/minute).

Conclusion. In this 12-week pilot study, HIIT improved multiple aspects of health in individuals with knee OA; larger studies are needed.

INTRODUCTION

Symptomatic knee osteoarthritis (OA) affects at least 16% of the United States population (1,2). Few effective treatments exist for knee OA; physical activity is a first-line strategy for the management of pain and mobility for affected individuals (3,4). Strong evidence supports aerobic and strengthening exercise programs for reducing pain and improving physical function in adults with knee OA (3,5–7), with effect sizes comparable to those reported for simple analgesics and nonsteroidal anti-inflammatory drugs (5). Unfortunately, most people with knee OA demonstrate mostly sedentary or inadequate physical activity behaviors (8,9). Existing exercise programs that are effective for knee OA can require considerable time to perform and require specific equipment (3,5–7). People with knee OA have the added barriers of pain and functional limitations that may make meeting recommended exercise (eg, 150 minutes each week) (10,11) intolerable. Furthermore, individuals may lack the time to perform these programs, and their initial excitement may quickly lessen, which can diminish the consistency and sustainability of physical activity habits (12). Knee OA is associated with other common comorbid conditions (eg, obesity, cardiovascular disease, and diabetes) (13–17), and finding physical activity approaches that can efficiently address more than one condition is particularly important for some individuals.

High-intensity interval training (HIIT) is an exercise approach that may overcome these barriers for people with symptomatic

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knee OA. HIIT is characterized by short vigorous bouts of intense exercise followed by rest periods. Prior research shows that performing HIIT two to three times per week (10 1-minute bouts with 1-minute rest periods) is sufficient to promote adherence and important physiological changes, such as improvements in cardiorespiratory health, body composition, and insulin sensitivity (18,19). HIIT has promising long-term adherence rates and offers similar physiological benefits as less intense long-duration exercise in a shorter period of time and with more pronounced effects on cardiorespiratory fitness (20,21). Time efficiency and flexibility of exercise mode (eg, walking and cycling) have supported the successful implementation of HIIT among individuals with obesity (22) and older adults (23).

Three prior pilot studies support the promise of HIIT interventions for the management of OA (24–26). Bressel et al (24) demonstrated improved pain and function among 18 participants with knee or hip OA after performing HIIT on an aquatic treadmill up to three times per week for 6 weeks; however, this intervention also included a balance training program, and, thus, the contribution of HIIT to these improved outcomes cannot be differentiated from that of the balance exercises. Keogh et al (25) conducted an 8-week unsupervised home-based program with four cycling sessions per week of HIIT versus moderate-intensity continuous training (MICT) among people with knee OA; compared with the MICT group (n = 8), those who completed HIIT (n = 9) had comparable improvements with self-reported pain and function and greater improvements in timed up and go. In our own prior study of 13 adults with symptomatic knee OA (26), knee pain and function improved after 6 weeks of twice weekly cycling HIIT. Additionally, there were improvements in cardiorespiratory fitness and metabolic changes that were suggestive of improved skeletal muscle energetics. These studies provide initial data supporting potential benefits of HIIT interventions for the management of pain and function among people with knee OA. However, questions remain about the feasibility and effects specifically of HIIT for knee OA, especially over a period of time longer than 6 to 8 weeks. The effects of HIIT on aspects of health other than knee pain or function are of particular interest because of the common comorbidities associated with knee OA.

The purpose of this feasibility and proof-of-concept study was to assess, among adults with symptomatic knee OA, the feasibility of a two session per week, 12-week HIIT program and the short-term changes (at 6 and 12 weeks) in functional, symptomatic, and physiological outcomes. Adverse events and changes in the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) pain, stiffness, and function subscales were primary outcomes (27,28). Although this study was not designed or powered for hypothesis testing, we anticipated that individuals with knee OA would have improvements in the WOMAC, physical function, balance, isometric knee extensor and flexor strength, cardiorespiratory fitness, and body composition after completing HIIT for 6 weeks and 12 weeks, respectively.

PATIENTS AND METHODS

Study design. This project was a single-arm study in which all participants received 12 weeks of the HIIT intervention. The 12-week duration was selected because it is comparable to those of other exercise intervention programs for knee OA (29). Potential participants were initially identified from university medical records based on International Classification of Diseases-10 codes for knee OA (M17.XX) and were mailed an introductory letter. Additionally, potentially eligible individuals from a list of prior laboratory studies were contacted; a recruitment email was also sent to university employees, faculty, and students. Individuals interested in the study were screened for eligibility criteria via telephone. Individuals who met the eligibility criteria (described below) and who were interested in participating met with a study team member to complete written informed consent prior to participating. Potential participants completed a 12-lead electrocardiogram, and the study physician reviewed test results and their medical history to clear individuals for participation in the study. All procedures were approved by the university's Biomedical Institutional Review Board. The study was registered with ClinicalTrials.gov (NCT03281668). Sets of functional, symptomatic, and physiological variables were included as outcomes to monitor initial changes related to the HIIT intervention. All participants completed these measures at baseline, 6 weeks, and 12 weeks.

Study participants. Participant enrollment occurred from November 1, 2017, to July 2, 2018. Men and women aged 40 to 75 years old with a body mass index (BMI) of 18.5 to 50 kg/m^2 with symptomatic knee OA were eligible to participate in this study (Figure 1). Symptomatic knee OA was defined as a self-report of physician diagnosis of knee OA and current knee symptoms in at least one knee determined from a minimum score of 6 of 20 on the pain subscale of the WOMAC.

Potential participants were excluded if they had self-reported fibromyalgia, rheumatoid arthritis, or other systemic rheumatic disease; had severe dementia or other memory loss condition; had an active diagnosis of psychosis or current uncontrolled substance abuse disorder; been hospitalized for a stroke, heart attack, or heart failure, or had surgery for blocked arteries in the past 3 months; had a total joint replacement knee surgery, other knee surgery, meniscus tear, or anterior cruciate ligament tear in the past 6 months; were on a waiting list for total joint replacement; had an intra-articular injection in past 3 months or scheduled during the study period; had severely impaired hearing or speech; were pregnant; had a serious or terminal illness as indicated by referral to hospice or palliative care; resided in a nursing home; or had any other health problems that would prohibit safe participation in the study. Because of the focus on the tolerance of HIIT and its initial effects on health outcomes, individuals were not enrolled if they were meeting Department of Health and Human Services Guidelines for Physical Activity (150 minutes per week) (10,11),

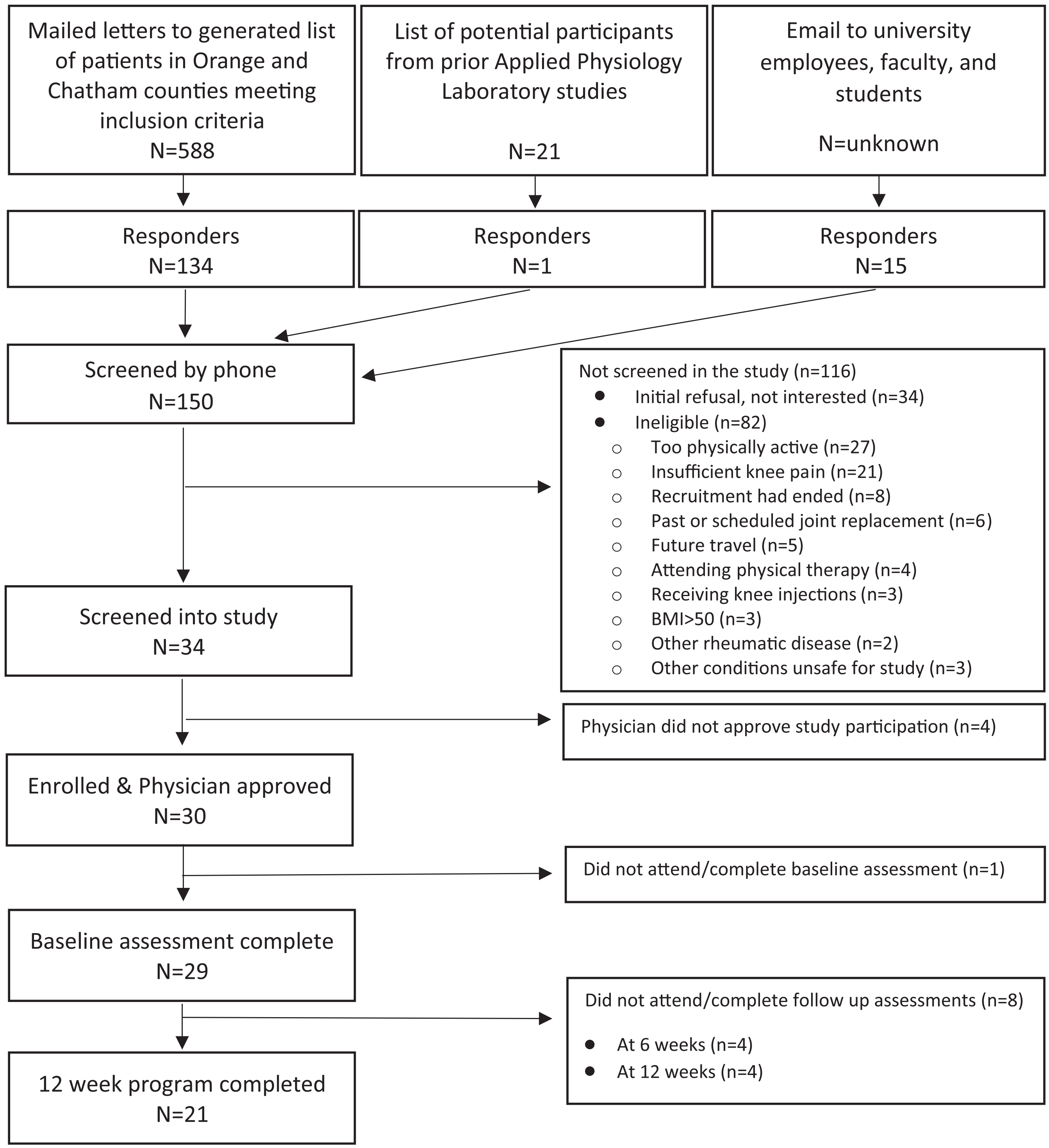

Figure 1. Participant flow diagram. BMI, body mass index.

currently doing HIIT, participating in physical therapy for knee OA, or currently participating in another OA intervention study.

Feasibility, adherence, and tolerability measures. The number of potential participants contacted was recorded as well as the number of responders to the initial contact, the number who completed screening, and the number of participants retained at the 6- and 12-week post-tests. Frequency and reasons for initial refusal, ineligibility, and dropout were collected. Adherence and tolerability were evaluated on the basis of the number of sessions attended/completed, modifications to mode, adverse events, and exercise enjoyment (rating of 1-7 in which 1 = "not at all" and 7 = "extremely" regarding enjoyment of the physical activity) on each training day from an item from the Physical Activity Enjoyment Scale (30).

Physical function. Performance-based tests consistent with the Osteoarthritis Research Society International recommendations (31–33) were used to assess physical function. These measures included the 20-m fast-paced walk test (in seconds), the 30-second chair-stand test (number of completed chair-stands recorded), a stair-climb test (number of seconds to ascend and descend 12 stairs), and the timed up and go test (in seconds).

Knee OA symptomatic burden. The WOMAC was used to assess knee OA symptomatic burden (27). The WOMAC includes a total of 24 items with subscales of pain (five items), stiffness (two items), and function (17 items), which are all rated on a Likert scale of 0 (no symptoms) to 4 (extreme symptoms). The total WOMAC score was calculated (score range of 0-96 [no to extreme problems]), as well as the pain (score 0-20), stiffness (score 0-8), and function (score 0-68) subscales. The reliability, validity, and responsiveness of the WOMAC pain and physical function subscales have been demonstrated among patients with knee OA (34,35).

Balance. Single leg stance time (the ability to stand on one limb unassisted) was recorded in seconds (maximum time = 30 seconds) (36).

Muscle strength. A HUMAC NORM isokinetic dynamometer (Computer Sports Medicine) was used to measure the isometric strength of knee flexors and extensors (37,38). The primary assessment of strength was set at 60 degrees of knee flexion, which was based on clinical relevance and evidence that persons with OA exhibit high correlations ($r > 0.7$) for assessments of isometric strength at varying angles (39). Three trials were completed, with the best of the three considered peak torque; isometric strength was determined from a 5-second hold while receiving visual feedback on a computer screen. Previously published standard error of measurement (SEM) values for quadriceps strength were 10.76 Nm (40).

Cardiorespiratory fitness. Peak oxygen consumption (VO_2peak), the gold standard for identifying aerobic fitness level and evaluating cardiovascular effects, was used to establish individual training intensity. All participants performed a ramp-based cycling ergometer test increasing 1 watt every 3 seconds, with respiratory gases continuously monitored with open-circuit spirometry using a calibrated metabolic cart (True One 2400®, Parvo-Medics) to determine VO_2peak and HIIT exercise workload. Data were averaged over 15-second intervals, with the average of the three highest values defined as VO_2peak. Maximum heart rate (in beats/minute), VO_2peak (liters/minute), and time to exhaustion (minutes) were recorded. Test-retest reliability from our laboratory for the VO_2peak protocol in the present study has demonstrated an intraclass correlation coefficient (ICC) of 0.98 and an SEM of 1.74 ml/kg/minute.

Body composition. Total body composition (fat mass, lean mass, fat percentage, visceral fat, and lower-body segmental lean mass [right and left leg]) was assessed using dual-energy x-ray absorptiometry (DXA) (Lunar iDXA, General Electric Medical Systems Ultrasound & Primary Care Diagnostics, enCORE Software, Version 16, General Electric). Each scan was performed by the same certified DXA technician. In our laboratory, the Lunar iDXA test-retest reliability values for fat mass, lean mass, and fat percentage have ICCs of 0.99, 0.99, and 0.99, respectively, and SEMs of 0.46 kg, 0.81 kg, 0.81%, respectively.

HIIT intervention. All training was conducted with one-on-one supervision from trained research personnel who were experienced with our HIIT protocol and were closely supervised by study investigators to ensure intervention fidelity. Participants chose the mode of exercise (eg, cycling or walking). Cycling was encouraged, but if the participant did not feel as though they were able to cycle or preferred not to, the treadmill was supported. Each training session included a 3- to 5-minute warm-up of low-intensity cycling or walking (depending on the chosen mode) followed by 10 repetitions of 1 minute of exercise at a given participant's 90% VO_2peak with 1-minute rest periods. A complete rest period was used rather than low- to moderate-intensity exercise to maximize effort on the work bout (and minimize additional joint stress) and maximize metabolite accumulation to support greater adaptations. The training occurred twice weekly for 12 weeks, with at least 24 hours in between training sessions, similar to prior protocols (41). Heart rate was monitored and recorded using chest strap heart rate monitors (Polar FT1, Polar USA). Participants were also instructed to keep outside activity consistent with what they were doing prior to study enrollment.

Analysis. All statistical analyses were completed using SAS System Software 9.4 (SAS Institute). Means and SDs for continuous variables and frequencies and percentages for categorical variables were calculated for demographic and clinical characteristics at baseline, 6 weeks, and 12 weeks. Separate multivariable-adjusted linear mixed models (LMMs) were fit for each outcome (eg, 20-m fast-paced walk test, 30-second chair-stand test, stair-climb test, timed up and go, WOMAC, single leg stand, isometric knee flexor and extensor strength, and VO_2peak) to calculate mean change estimates and 95% confidence intervals (CIs), adjusting for fixed effects of categorical time, continuous age, sex, and continuous baseline BMI. If $P < 0.1$, quadratic effects of age and BMI were included the models. LMMs were fit using PROC MIXED (SAS/STAT, SAS Institute) with one RANDOM statement including a random intercept at the participant level (option SUBJECT = participant). An unstructured covariance matrix for correlations over time was indicated in the RANDOM statement. We used the containment method to compute denominator degrees of freedom and restricted maximum likelihood estimation methods of variance parameters. Missing data were assumed to be missing at random. The mean change between baseline, 6-week, and 12-week assessments was estimated for each outcome.

RESULTS

Feasibility, adherence, and tolerability measures. Figure 1 shows the participant flow for this study. Of the 29 participants who completed baseline assessments (Table 1), 25 completed the first 6 weeks of sessions and 6-week assessments, and 21 completed the full 12-week HIIT program and final assessments. Compared with those who completed the study (n = 21) (Table 1), those who did not complete the 12-week program (n = 8) had a higher BMI, a slightly higher fat mass, and lower baseline physical function. Two-thirds (n = 14) of participants who completed the 12-week HIIT program attended all 24 sessions (mean: 23.3; SD: ±1.2; range: 20-24 sessions).

The majority of participants used cycling as their only mode of exercise throughout the entire study. Because of stiffness and range of motion, three participants walked on a treadmill at 90% maximum heart rate (based on rate obtained during VO_2peak) for the duration of the study (n = 1), or the first 6 weeks of training (n = 2); range of motion improved and stiffness was reduced after the first 6 weeks, enabling them to train on a cycle ergometer for the later 6 weeks. Over the course of the study, participants reported that they had high enjoyment (5 = "quite a bit", 6 = "very much", and 7 = "extremely") for approximately two-thirds of their completed sessions. The eight participants who discontinued participation did not have any adverse events related to the HIIT program. Reasons for discontinuation included knee swelling and pain from work-related activities (n = 1), family circumstances (n = 1), medication change for condition unrelated to the study (n = 1), undisclosed choice to discontinue HIIT program (n = 2), scheduling conflicts (n = 1), and sprained ankle doing yard work and could not continue HIIT program (n = 1), and one participant was lost to follow-up (no response to calls and reminders).

Outcomes. Table 2 includes descriptive statistics on each outcome measure over assessment visits at baseline, 6 weeks, and 12 weeks. From baseline to 6 weeks, statistically significant improvements occurred for the 20-m fast-paced walk test (mean effect [95% CI] = –0.79 [–1.24 to –0.34] seconds), the 30-second chair-stand test (1.6 [0.9-2.3] chair-stands), the stair-climb test (–0.98 [–1.65 to –0.30] seconds), the timed up and go test (–0.49 [–0.83 to –0.15] seconds), isometric knee extensor strength (right knee: 9.36 [1.58-17.14] Nm; left knee: 9.24 [0.25-18.23] Nm), VO_2peak (0.18 [0.08-0.28] L/minute), and time to exhaustion (0.89 [0.48-1.29] minutes) (Table 3). Between 6 and 12 weeks, statistically significant improvements were noted for the 30-second chair-stand test (1.0 [0.2-1.8] number of chair-stands), and statistically significant changes were observed for the WOMAC total score (–5.2 [–9.6 to –0.8]) (driven by significant improvements in the stiffness and function subscales), the right knee flexor isometric strength (5.18 [1.10-9.27] kg), and the maximum heart rate (3.0 [0.1-6.0] beats/minute). From baseline to 12 weeks, statistically significant improvements occurred for all performance-based physical function measures, the WOMAC score (total and all subscales),

Table 1. Participant characteristics among participants with symptomatic knee osteoarthritis by study visit

	Assessment Visit		
Characteristic	Baseline (N = 29)	6 Wk (N = 25)	12 Wk (N = 21)
Male sex, n (%)	10 (34.5)	10 (40.0)	9 (42.9)
Age group at consent, n (%)			
40-49 y	1 (3.4)	1 (4.0)	1 (4.8)
50-59 y	8 (27.6)	8 (32.0)	7 (33.3)
60-69 y	15 (51.7)	12 (48.0)	9 (42.9)
≥70 y	5 (17.2)	4 (16.0)	4 (19.1)
Race/ethnicity, n (%)			
White	18 (62.1)	17 (68.0)	14 (67.7)
Black	7 (24.1)	5 (20.0)	4 (19.1)
Hispanic	2 (6.9)	2 (8.0)	2 (9.5)
Other	1 (3.4)	1 (4.0)	1 (4.8)
Prefer not to answer	1 (3.4)	0 (0.0)	0 (0.0)
BMI category, n (%)			
Healthy weight (18.5-24.9 kg/m^2)	5 (17.2)	5 (20.0)	5 (23.8)
Overweight (25.0-29.9 kg/m^2)	5 (17.2)	5 (20.0)	5 (23.8)
Obesity class I (30.0-34.9 kg/m^2)	9 (31.0)	8 (32.0)	7 (33.3)
Obesity class II (35.0-39.9 kg/m^2)	6 (20.7)	6 (24.0)	4 (19.0)
Obesity class III (≥40.0 kg/m^2)	4 (13.8)	1 (4.0)	0 (0.0)

Abbreviation: BMI, body mass index.

Table 2. Outcome measures among participants with symptomatic knee OA by study visit

	Assessment Visit								
	Baseline			6 Weeks			12 Weeks		
Outcome Measure	n	Mean	SD	n	Mean	SD	n	Mean	SD
Performance-based physical function									
20-m fast-paced walk test, seconds[a]	29	12.5	5.4	25	11.5	5.0	21	10.0	2.8
30-second chair-stand test, n	29	12.6	5.4	25	14.5	6.1	20	16.4	6.4
Stair-climb test, seconds	28	13.8	7.3	24	11.5	6.4	21	10.6	6.2
Timed up and go test, seconds[a]	21	7.9	4.8	22	7.3	4.4	21	6.0	1.4
Knee OA symptomatic burden									
WOMAC pain subscale (0-20)	29	6.4	2.9	25	5.8	3.8	21	4.2	3.0
WOMAC stiffness subscale (0-8)	29	3.8	1.4	25	3.4	1.7	21	2.4	1.4
WOMAC function subscale (0-68)	29	22.2	10.6	25	19.6	14.4	21	13.4	9.9
WOMAC total score (0-96)	29	32.4	14.0	25	28.8	19.2	21	20.0	13.7
Balance									
Single leg stand (maximum = 30 seconds), seconds	29	15.1	11.0	25	19.2	11.6	21	21.0	11.9
Muscle strength: isometric strength									
Flexor									
Right knee (average), Nm	28	71.1	33.4	25	72.5	36.5	21	77.8	37.9
Right knee (maximum), Nm	28	75.3	35.7	25	75.5	37.4	21	83.1	40.7
Left knee (average), Nm	28	68.3	35.0	25	72.2	37.3	21	72.1	33.5
Left knee (maximum), Nm	28	73.1	38.8	25	76.1	38.7	21	75.9	35.5
Extensor									
Right knee (average), Nm	28	122.3	51.5	25	136.2	55.9	21	140.6	58.1
Right knee (maximum), Nm	28	129.8	53.5	25	142.7	57.6	21	147.2	58.9
Left knee (average), Nm	28	114.5	50.7	25	125.8	63.1	21	129.0	62.2
Left knee (maximum), Nm	28	120.8	52.1	25	132.3	68.5	21	136.4	62.1
Cardiorespiratory fitness									
VO_2peak, L/minute	29	2.1	0.7	24	2.3	0.9	21	2.3	0.9
Time to exhaustion, minutes	28	8.3	2.6	24	9.5	3.0	21	9.9	3.0
Maximum heart rate, beats/minute	29	147.6	19.9	25	149.1	20.2	20	154.5	19.7
Body composition									
Lean mass, kg	29	51.4	11.8	25	52.2	12.1	21	51.6	12.6
Fat mass, kg	29	36.2	13.0	25	34.7	13.1	21	32.1	10.9
Visceral fat, kg	29	3.8	2.7	25	3.6	2.6	21	3.1	2.3
Right leg lean mass, kg	29	9.6	2.4	25	9.9	2.5	21	9.8	2.5
Left leg lean mass, kg	29	9.4	2.3	25	9.7	2.6	21	9.7	2.5
Fat percentage, %	29	39.2	8.0	25	38.4	8.4	21	36.9	8.0

Abbreviation: OA, osteoarthritis; VO_2peak, peak oxygen consumption; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.
[a] Average of two trials used. Greater times on performance-based physical function measures indicates poorer performance.

single leg stand (3.41 [0.26-6.56] seconds), isometric knee extensor strength, VO_2peak, time to exhaustion, and maximum heart rate. Body composition measure changes were not statistically significant (Table 3).

DISCUSSION

This pilot study examined the feasibility, adherence, tolerability, and changes in outcomes of a supervised 12-week HIIT program among individuals with symptomatic knee OA. Recruitment for this study was feasible and aligned with our anticipated enrollment rate. Adherence was good for the first 6 weeks of the program (83% of participants completed 6 weeks of supervised HIIT), with a slightly lower fidelity at 12 weeks (70%), comparable with other in-person exercise programs. Most participants enjoyed the HIIT program, and no adverse events related to the HIIT program were reported.

Improvements were noted for all four physical function measures, isometric knee extensor strength, VO_2peak, and time to exhaustion at 6 weeks, and these improvements continued at 12 weeks. At 12 weeks, improvements were observed for the WOMAC and single leg stand. Of these results, the change from baseline to 12 weeks in the 20-m fast-paced walk test (increased speed by ~0.2 m/second) and 30-second chair-stand test (increased by 2-3 chair-stands). The ~6% increase in VO_2peak from baseline to 12 weeks is consistent with clinically relevant improvements (42). The VO_2peak and time to exhaustion findings are comparable with results from our previous study (26). Improved knee extensor strength in the present study could explain improvements in physical function observed in this study (43,44). Isometric knee flexor strength did not show significant

Table 3. Adjusted mean estimates and 95% CIs of change in assessment measure outcome over time using separate models for each outcome

Outcome (Each a Separate Model)	Visit Effect: 6-Week Change From Baseline	Visit Effect: 12-Week Change From Baseline	Visit Effect: 6-Week to 12-Week Change
Physical function			
20-m fast-paced walk test, seconds	−0.79 (−1.24 to −0.34)	−1.13 (−1.61 to −0.64)	−0.33 (−0.81 to 0.15)
30-second chair-stand test, n	1.6 (0.9 to 2.3)	2.6 (1.8 to 3.4)	1.0 (0.2 to 1.8)
Stair-climb test, seconds	−0.98 (−1.65 to −0.30)	−1.42 (−2.13 to −0.71)	−0.44 (−1.16 to 0.27)
Timed up and go test, seconds	−0.49 (−0.83 to −0.15)	−0.58 (−0.95 to −0.22)	−0.10 (−0.44 to 0.24)
Knee OA symptomatic burden			
WOMAC pain subscale (0-20)	−0.6 (−1.7 to 0.4)	−1.7 (−2.8 to −0.6)	−1.1 (−2.2 to 0.1)
WOMAC stiffness subscale (0-8)	−0.4 (−0.9 to 0.0)	−1.2 (−1.7 to −0.7)	−0.8 (−1.3 to −0.2)
WOMAC function subscale (0-68)	−2.9 (−5.9 to 0.1)	−6.3 (−9.6 to −3.1)	−3.4 (−6.7 to −0.2)
WOMAC total score (0-96)	−4.0 (−8.1 to 0.0)	−9.2 (−13.6 to −4.9)	−5.2 (−9.6 to −0.8)
Balance			
Single leg stand (maximum = 30 seconds), seconds	2.78 (−0.17 to 5.73)	3.41 (0.26 to 6.56)	0.63 (−2.55 to 3.80)
Muscle strength: isometric strength			
Knee flexors			
Right knee, maximum, Nm	−1.85 (−5.72 to 2.02)	3.34 (−0.74 to 7.41)	5.18 (1.10 to 9.27)
Left knee, maximum, Nm	1.39 (−3.85 to 6.64)	−0.84 (−6.36 to 4.69)	−2.23 (−7.78 to 3.32)
Knee extensors			
Right knee, maximum, Nm	9.36 (1.58 to 17.14)	9.99 (1.80 to 18.18)	0.63 (−7.61 to 8.86)
Left knee, maximum, Nm	9.24 (0.25 to 18.23)	9.86 (0.40 to 19.33)	0.62 (−8.89 to 10.14)
Cardiorespiratory fitness			
VO_2peak, L/minute	0.18 (0.08 to 0.28)	0.14 (0.03 to 0.24)	−0.04 (−0.15 to 0.07)
Time to exhaustion, minutes	0.89 (0.48 to 1.29)	1.07 (0.63 to 1.50)	0.18 (−0.26 to 0.62)
Maximum heart rate, beats/minute	1.5 (−1.3 to 4.2)	4.5 (1.5 to 7.5)	3.0 (0.1 to 6.0)
Body composition			
Lean body mass, kg	0.22 (−0.19 to 0.63)	−0.12 (−0.56 to 0.31)	−0.35 (−0.78 to 0.09)
Fat mass, kg	−0.46 (−1.23 to 0.30)	−0.28 (−1.10 to 0.54)	0.19 (−0.63 to 1.01)
Visceral fat, kg	−0.14 (−0.33 to 0.05)	−0.19 (−0.40 to 0.02)	−0.05 (−0.26 to 0.15)
Right leg, lean mass, kg	0.12 (−0.04 to 0.28)	0.11 (−0.06 to 0.28)	−0.01 (−0.18 to 0.16)
Left leg, lean mass, kg	0.18 (−0.03 to 0.40)	0.23 (−0.00 to 0.46)	0.05 (−0.18 to 0.28)
Fat percentage, %	0.08 (−0.44 to 0.60)	0.11 (−0.44 to 0.66)	0.03 (−0.53 to 0.58)

Abbreviation: CI, confidence interval; VO_2peak, peak oxygen consumption; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.
Linear mixed models were adjusted for fixed effects of time, age, sex, and baseline body mass index and random intercepts.

changes from baseline to 6 or 12 weeks. The difference in the changes between knee extensor and flexor strength in this study may be due to the cycling mode, which relies on a pushing motion of the pedals that is primarily done by engaging the knee extensors. Measures of body composition did not show statistically important changes after the 12-week program. A previous 8-week home-based HIIT cycling program for people with knee OA also did not find significant changes in body composition (25), but our prior 6-week HIIT program showed improvements in left leg mass, similar to the current study (26).

Differences in outcome measures and heterogeneity in intervention frequency, type, intensity, and duration limit the comparison of effects across 12-week-long aerobic exercise interventions for knee OA. However, general comparisons can be made between the WOMAC pain and function score results from this study and other similar interventions. In a meta-analysis by Wang et al (45), 3 months of aerobic exercise was shown to improve WOMAC function scores (~10.5 change on a 68-point subscale), which is somewhat greater than the 6.3 score change seen in the present study. Two studies (46,47) of 12 weeks of moderate-intensity cycling exercise for people with knee OA (2-3 sessions/week of 45-60 minutes of cycling) demonstrated slightly better improvements in WOMAC pain scores than the present study (~2-3 versus 1.7 on a 20-point subscale, respectively), but improvements in WOMAC function scores were comparable (score change of ~6 versus 6.3 on a 68-point subscale). For individuals with knee OA with limited time to exercise, HIIT may be an alternative aerobic exercise option because of the potential to provide improvements in function in shorter-duration sessions than moderate-intensity interventions.

The numerous changes in outcomes that occurred in the first 6 weeks were notable and are consistent with other studies showing improvements in pain, balance, physical function, and mobility for adults with OA participating in HIIT programs lasting 6 to 8 weeks (24–26). Considering that physical activity guidelines recommend at least 75 minutes of vigorous-intensity exercise per week, it is noteworthy that 20 minutes per week of the HIIT program in this study resulted in improvements for several functional, symptomatic, and physiological outcomes. There were additional improvements in outcomes that occurred between 6 and 12 weeks, which supports future investigation of HIIT over a longer duration to determine whether improvements are maintained or whether they continue to provide further beneficial changes. Because of the importance of physical activity for the long-term management of OA and comorbid conditions, it is necessary to examine an HIIT intervention over a duration that may promote sustainable behavior change, such as a 12 to 18 month study that includes 3 months of supervised exercise followed by a home program, similar to other exercise intervention studies for OA (3,29,48,49).

The present study has several strengths; the diversity of the sample by race, age, and sex and the wide range of BMIs among participants increase the generalizability of study findings to real-world patients with symptomatic knee OA. The HIIT program had a well-established protocol and was tailored to each participant on the basis of their capabilities and mode preference, which helped minimize adverse events and enhanced exercise adherence. The duration and frequency of this HIIT program has previously been shown to be sufficient to promote adherence and important physiological changes (50). Offering one-on-one supervision and coaching also helped with adherence and progression of the training.

There were some limitations with this study. This was a single-arm study, so it is not known how HIIT for knee OA compares with other exercise approaches. The first assessment of outcomes were conducted at 6 weeks; health benefits from HIIT may occur in less than 6 weeks based on studies in other populations that demonstrate improvements in cholesterol (51,52) and insulin sensitivity (53,54) after only 2 weeks of HIIT. Future research should assess pain and function more frequently and sooner (ie, after 2 weeks of HIIT) among individuals with OA. Improvements in pain and function during the early weeks of HIIT could motivate individuals with knee OA to continue and progress their HIIT program over the long term. Diet and caloric intake were not monitored in the present study, and, potentially, participants may have increased dietary intake in response to increased physical activity, which may limit the potential for change in fat mass or visceral fat. Also, 12 weeks of such low-volume exercise may not have provided enough volume to stimulate changes in body composition with HIIT in this group of participants who were predominantly overweight and obese.

In summary, a 12-week supervised HIIT program improved WOMAC scores, physical function, balance, isometric knee extensor strength, and cardiorespiratory fitness, with most changes occurring as early as 6 weeks. Future studies of individuals with symptomatic knee OA should consider a supervised protocol during the initial weeks of an HIIT program to enhance adherence and tolerability while participants are learning and becoming comfortable with this exercise approach. The next phase of this research should determine when and how to transition individuals with knee OA to an independent home-based progressive HIIT program that they can successfully sustain. Larger randomized controlled trials are needed to examine the feasibility, effectiveness, and potential for adverse effects of an HIIT program long term, particularly one that includes a transition to a home exercise program, and to further determine which symptomatic knee OA subpopulations may best tolerate and benefit from this physical activity approach.

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AUTHOR CONTRIBUTIONS

All authors were involved in drafting the article or revising it critically for important intellectual content, and all authors approved the final version to be published. Drs. Golightly and Smith-Ryan had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.
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