Roxburgh et al. (2024) *Int J Res Ex Phys*. 19(2):57-77.

Sponsored by:
Exercise and Sport Science Program
Western Colorado University

International Journal of Research in Exercise Physiology

Original Research Article

Maintenance of Preoperative Fitness by Home-Based Prehabilitation Following Supervised Prehabilitation in Patients Awaiting Total Hip or Knee Arthroplasty

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Abstract

Background: Prehabilitation is the process of optimising patient functional capacity and health status in preparation for surgery. Supervised prehabilitation is considered gold standard, however it is resource intensive. The purpose of this study was to examine the effect of a personalised home-based exercise intervention, for maintaining cardiorespiratory fitness and physical and mental health, after completion of a supervised prehabilitation intervention. **Methods:** Eighteen participants awaiting total hip or knee arthroplasty who had completed a prior supervised prehabilitation programme and not had their surgery scheduled, performed a 12-week home-based physical activity or exercise intervention. Assessment of peak oxygen consumption, anaerobic threshold and resting blood pressure were performed pre- and post-supervised prehabilitation and post-maintenance. **Results:** Peak oxygen consumption increased by 12% following supervised prehabilitation ($p = 0.014$) but decreased by 9% following maintenance ($p = 0.007$). Anaerobic threshold increased 15% across supervised prehabilitation ($p = 0.013$) and remained 11% higher after maintenance ($p = 0.009$). Mean resting systolic blood pressure decreased by 14 mm Hg across supervised prehabilitation ($p = 0.001$) and remained 9 mm Hg lower post-maintenance ($p = 0.032$). **Conclusion:** Home-based maintenance was not effective for maintaining improvements in peak oxygen consumption following supervised prehabilitation; however, anaerobic threshold was increased above surgical prognostic cut-offs and maintained with the maintenance intervention. This study provides preliminary evidence for maintaining some fitness and health measures using a relatively low-cost and safe delivery of prehabilitation.

Key Words: Anaerobic Threshold, Home-based Exercise, Maintenance, Osteoarthritis, Prehabilitation, Peak Oxygen Consumption, Total Joint Arthroplasty.

Introduction

Patients can experience prolonged waiting periods (e.g., > 12 months) for surgery due to the nature of surgical waitlisting (e.g., staff limitations, lack of hospital beds)[1,2]; these delays have been exacerbated by demands on the healthcare system following the SARS-CoV-2 pandemic. Prehabilitation is the process of optimising patient functional capacity and health status in preparation for surgery [3]. Patients with higher functional capacities have greater resilience to the stress of surgery and are at lower risk of surgical-related complications [3]. Therefore, prehabilitation is recommended for patients to productively utilise this waitlisting period. Although an extended waitlist period could theoretically allow for longer and potentially more efficacious prehabilitation, programmes are typically of a fixed duration and surgical delays or cancellations can impact prehabilitation delivery. Therefore, it is a challenge to deliver prehabilitation at the optimal time as benefits may be lost if the programme is not maintained until the surgery date.

Supervised prehabilitation is considered "gold standard", however it requires a large resource investment (financial, personnel, equipment, transport) and time commitment [4]. Typical programmes involve exercise training, nutritional and psychological support. From a patient perspective, the most commonly reported barriers to participating in supervised prehabilitation are related to transport (finding and paying for parking) and perceived lack of time [5]. Additionally, many tertiary hospitals service a wide geographical area, therefore travelling long distances for supervised prehabilitation is not feasible for many patients. These barriers can negatively impact participation and the effectiveness of prehabilitation [5].

From a public health perspective, community or home-based prehabilitation is an attractive alternative, reducing demand on finite healthcare resources and potentially lessening the aforementioned barriers. In the context of surgical delays, patients would have the flexibility to cease / resume their prehabilitation around a surgical date and are not bound by any bureaucratic or logistical constraints of a formal programme. However, non-supervised prehabilitation typically is not as effective as supervised prehabilitation [6].

A potential strategy is offering a short-term "intensive" and supervised period of prehabilitation, followed by an unsupervised community- or home-based phase to maintain improvements until surgery. The period of supervised prehabilitation provides an opportune time for education and patient empowerment to be active preoperatively and postoperatively. Initiation of an exercise programme after a period of sedentarism is recognised as a higher-risk period for cardiovascular and musculoskeletal injury [7]; therefore, from a safety perspective, an initially-supervised programme is preferable given the vulnerability and comorbidities of many surgical patients. Further advantages of a supervised programme are the support of an exercise specialist, who can take into account the exercise and medical history of individual patients [8] and build rapport for continued support via telemedicine in the home phase. Transitioning to a home phase removes the necessity and cost of transportation and patients have the ability to perform the prehabilitation in their own time, and to cease or continue as dictated by the booking of their surgical procedure.

One study in a cardiac rehabilitation setting has shown that maintenance of cardiorespiratory fitness (i.e., peak oxygen consumption) in an unsupervised setting is possible [9]. Notably, Butler and co-workers utilised a pedometer-guided home-based intervention that was able to increase the anaerobic threshold following supervised training [10]. Whilst previous work in our lab has shown that preoperative cardiorespiratory fitness can be improved with supervised prehabilitation (high-intensity interval training; HIIT) [11], to date no published research has investigated the ability to maintain cardiorespiratory fitness following supervised prehabilitation.

Therefore, the purpose of this study was to examine the effect of a personalised home-based exercise intervention for *maintaining* physical and mental health after completion of a standard supervised prehabilitation intervention in individuals with osteoarthritis awaiting total hip or knee arthroplasty. Specifically, the aims of the study were to assess: 1) the effect of the intervention on maintenance of peak oxygen consumption (peak $\dot{V}O_2$) and the anaerobic threshold, following supervised prehabilitation; 2) the effect of the intervention on maintenance of other measures of physical and subjective health; and 3) adherence and safety of the intervention. We hypothesised that peak $\dot{V}O_2$ would not be different when compared at completion of supervised prehabilitation and with completion of the home-based maintenance intervention.

Methods

This study was a prospective intervention study examining the effect of a home-based exercise intervention, following 12 weeks of supervised prehabilitation on maintenance of cardiorespiratory fitness and physical and mental health in patients with severe lower-limb osteoarthritis awaiting total hip or knee arthroplasty. Recruitment for this study occurred between June 2020 and June 2021.

Following completion of a 12-week prehabilitation program (detailed in [11,12] and in brief below), eligible and consenting participants were provided an individualised exercise intervention to be performed at home or in the community (Maintenance). The maintenance intervention was initiated the day after the 12-week assessment. After 12 weeks of Maintenance participants were reassessed.

Ethical approval for this study was obtained from the Health and Disability Ethics Committee (18/NTA/148) and the study conformed to the standards set by the Declaration of Helsinki. The trial was registered with the Australia New Zealand Clinical Trials Registry (ACTRN12618001358235). All participants provided written and informed consent.

Study participants

Participants who completed a prior supervised prehabilitation programme [11], and had not yet had their total hip or knee arthroplasty scheduled (i.e., no confirmed surgical date) were invited to participate in this study. In brief, these participants completed 12 weeks of supervised prehabilitation consisting of either hot-water immersion (3 x per wk, 20-30 min chest-deep immersion in 40°C water, followed by ~15 min of light-resistance exercise) or high-intensity interval training (HIIT; 3 x per wk, 6-8 x 60-s intervals at ~100% peak $\dot{V}O_2$; 60-90 s recovery at very low intensity) on an elliptical cross-trainer or arm ergometer) [11].

Experimental procedures

All measures were collected at baseline (i.e., before supervised prehabilitation, or T0), at the end of supervised prehabilitation (referred to as post-prehabilitation or T1) and following the Maintenance intervention (referred to as post-maintenance or T2). Anthropometric measures including height (stadiometer, Wedderburn WS-HRP, Auckland, New Zealand), body mass (scales, Seca, Hamburg, Germany) and body composition (bioimpedance analysis, InBody 230, Seoul, South Korea) were obtained. Participants then lay supine for at least 10 min and resting heart rate was collected via 3-lead electrocardiogram (lead II position; FE132, ADInstruments, Dunedin, New Zealand). Resting blood pressure was then collected per American Heart Association guidelines using a sphygmomanometer (Welch Allyn DS66, New York, USA) [13]. In brief, an appropriately sized cuff was fitted to the participant's left arm with measurement completed twice and averaged; a third measure was performed if systolic and/or diastolic BP differed by ≥5 mm Hg, and a median calculated. A maximal symptom-limited cardiopulmonary exercise test (CPET) was performed on either an elliptical cross-trainer or arm ergometer following procedures and analysis described previously [14]. Within participants, all three CPETs (i.e., at before supervised prehabilitation - T0, after supervised prehabilitation - T1 and post-maintenance – T2) were performed on the same modality. The 30-s sit-to-stand test, 30-s arm curl test and timed up-and-go test were performed as measures of physical function, adhering to established procedures [15]. Lower-limb isometric muscle strength was assessed using hand-held dynamometry (MicroFet2, Salt Lake City, USA) as previously described [16]. Knee joint range of motion (ROM) was measured using a goniometer across three consecutive trials and the maximum value used for analysis [17]. Qualitative measures assessed perceived physical function (Duke Activity Status Index; DASI [18]), quality of life (Short Form-12; SF-12 [19], EuroQual-5D; EQ-5D [20]) and impact of osteoarthritis (Oxford hip score; OHS / Oxford knee score; OKS [21]). Seven-day accelerometery assessed physical activity and time spent sedentary (activPAL3c, Glasgow, Scotland).

Maintenance intervention

Participants were provided a validated pedometer (HJ-005, OMRON, Kyoto, Japan) [22,23]. Advice was given to steadily increase daily step count (determined from average step count across week one of the Maintenance intervention) by 10% every 4 weeks [24]. Participants were asked to wear the pedometer from waking until going to bed and to maintain a log of daily step count. A study researcher contacted each participant every four weeks to offer support and to update their exercise prescription. Where a participant had access to exercise equipment / facilities, a personalised exercise programme (based on the participant's peak $\dot{V}O_2$, joint pain, etc.) was prescribed. The training regimen followed American College of Sports Medicine recommendations for aerobic exercise in adults with osteoarthritis [7], that recommend accumulating at least 150 min of activity each week. All participants were provided a rating of perceived exertion (RPE) scale and instructed to progress exercise intensity to a limit of 5/10 (i.e., "Hard") across each session and to avoid excessive increases in acute joint pain [25]. The Maintenance phase lasted for 12 weeks.

Data analysis

Prior to formal analysis, breath-by-breath data was exported via the software package (Quark CPET v. 1.6.7, COSMED, Rome, Italy) as a 20-s time average, to reduce the influence of physiological 'noise' [26,27]. All CPET data analysis was performed independently by two researchers using Excel (v 16.33, Microsoft, Redmond, WA, USA). The maximum 20-s average value for $\dot{V}O_2$ was used to determine peak $\dot{V}O_2$ [26,28]. The oxygen uptake efficiency slope (OUES) was calculated as the slope derived from $\dot{V}O_2$ (y-axis) and the log transformation of minute ventilation ($\dot{V}E$; x-axis) [29]. Anaerobic threshold was determined using the V-slope method and confirmed using plots of the ventilatory equivalents for oxygen and carbon dioxide, and end-tidal oxygen and end-tidal carbon dioxide, as functions of $\dot{V}O_2$ [30].

Statistical analysis

Statistical analysis was performed using R (version 4.1.1, R Development Core Team) and graphed using Prism (v9.3.0, GraphPad, San Diego, USA). Descriptive data were expressed as raw mean (SD) or number (proportion). A one-way repeated-measures analysis of variance tested for significant differences in baseline (i.e., T0), post-prehabilitation (i.e., T1) and post-maintenance (i.e., T2) primary (i.e., peak $\dot{V}O_2$) and secondary (i.e., other CPET, cardiovascular, anthropometric, functional, physical activity and patient reported outcome) variables. Post-hoc testing using Tukey's Test was performed if statistical significance ($p < 0.05$) was observed, to elucidate differences between time points. When the assumption of sphericity was violated, Greenhouse-Geisser's adjustment was used. A check for normality of residuals was performed for each variable by visually inspecting Q-Q plots and assessed formally using a Shapiro-Wilk test; where normality or homogeneity of variance was violated for a variable, raw data were log transformed for statistical analysis.

Results

Participant characteristics

Eighteen participants completed baseline assessment (T0), post-prehabilitation assessment (T1) and post-maintenance assessment (T2) (Figure 1). Participants' descriptive characteristics are listed in Table 1.

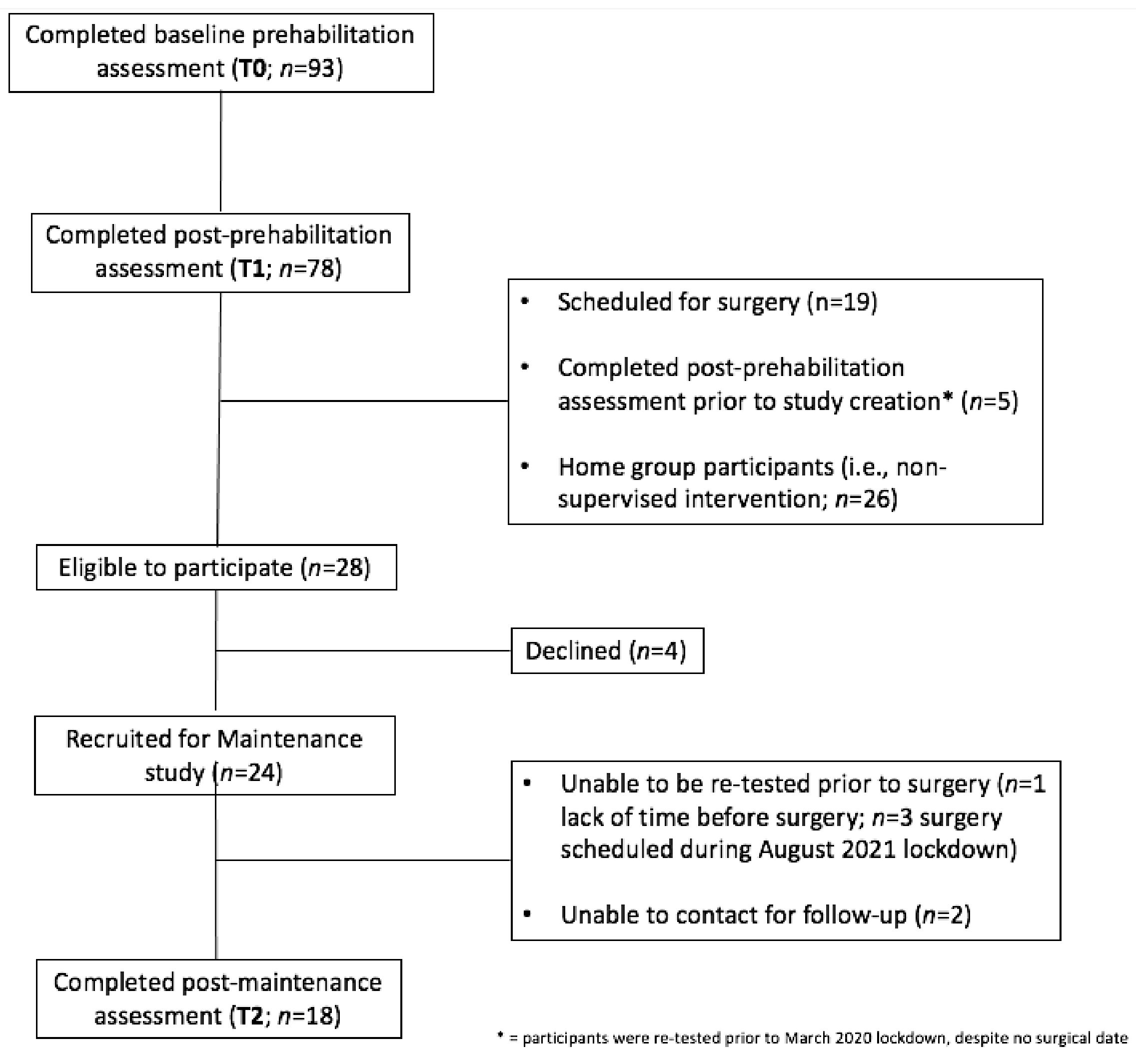

Figure 1. Study flow diagram.

Table 1. Descriptive statistics of participants.

Variable	Participants (*n*=18)
Age (y)	72 (7)
Male / female	7 (39%) / 11 (61%)
Height (cm)	163 (7)
BMI ($kg{\cdot}m^{-2}$)	31.7 (5.3)
Ethnicity	
NZ European / European	18 (100%)
Māori	1 (6%)
Arthroplasty site	
Hip	4 (22%)
Knee	14 (78%)
Comorbidity	
Previous myocardial infarction	4 (22%)
Previous stroke	2 (11%)
Dyslipidaemia	8 (44%)
Hypertension	13 (72%)
Obesity	10 (56%)
Diabetes mellitus / pre-diabetes	4 (22%)

Data are mean (SD) or as an absolute number with the percentage (%) of the whole. BMI = body mass index; NZ = New Zealand.

Intervention details

Participants completed an individualised pedometer-based programme (*n*=15) or individualised exercise using equipment at home or in the community (i.e., gym: *n*=1 , cycling: *n*=2). All participants completed the entire 12-week intervention (i.e., none had their surgery scheduled during the maintenance phase).

Participants who completed the pedometer-based intervention performed a mean of 5295 steps/day in week one and this increased by 11% at week 4 (5883 steps/day), another 5% at week 8 (6164 steps/day) and a further 7% at week 12 (6565 steps/day). Participants who used exercise equipment completed an average of 25 min, 3 sessions per wk at a reported RPE of 5/10 (i.e., "hard") throughout the 12 weeks. No adverse events or safety concerns were reported during the intervention.

Peak oxygen consumption (peak $\dot{V}O_2$)

Mean peak $\dot{V}O_2$ is presented in Table 2 and individual changes in Figure 2. Absolute peak $\dot{V}O_2$ increased by 12% across T0 to T1 ($p = 0.014$) regardless of the prehabilitation intervention group, but decreased by 9% across T1 to T2 ($p = 0.007$). For the 8 participants who performed HIIT during prehabilitation (i.e., T0 to T1), peak $\dot{V}O_2$ increased by 25% ($p = 0.002$); however peak $\dot{V}O_2$ decreased by 13% across T1 to T2 (p =

0.046) and was no longer statistically higher than T0 ($p = 0.099$). For the 10 Heat participants, peak $\dot{V}O_2$ did not change across T0 to T1 ($p = 0.811$), but decreased by 5% during maintenance ($p = 0.030$). Neither peak respiratory exchange ratio nor peak heart rate were different between groups across the interventions.

Other CPET variables

Other CPET variables are presented in Table 2. Anaerobic threshold increased 15% across T0 to T1 ($p = 0.013$) and at T2 this was still 11% higher than T0 ($p = 0.009$) (Figure 3). No change was evident in oxygen pulse, peak power output or OUES across time.

Table 2. Exercise variables at baseline (T0), post-prehabilitation (T1) and post-Maintenance (T2).

Variable	T0 (*n*=18)	T1 (*n*=18)	T2 (*n*=18)	Time effect (p-value)
Peak exercise				
$\dot{V}O_2$ (mL·min^{-1})	1504 (545)	1679 (607)*	1532 (619)†	**0.008**
$\dot{V}O_2$ (mL·min^{-1}·kg^{-1})	18.1 (6.5)	20.4 (7.3)	18.2 (6.9)†	**0.038**
Heart rate (b·min^{-1})	128 (17)	132 (16)	132 (14)	**0.008**
Oxygen pulse (mL·beat^{-1})	13.2 (4.1)	13.6 (4.6)	12.8 (4.5)	0.186
RER	1.10 (0.10)	1.09 (0.06)	1.08 (0.08)	0.762
Power output (watts)	57 (30)	75 (44)	66 (44)	**0.067**
OUES (L·min·O_2· L·min·log$\dot{V}$E)	1739 (659)	1852 (646)	1778 (748)	0.198
Anaerobic threshold				
$\dot{V}O_2$ (L·min^{-1})$^{\$}$	942 (258)	1081 (375)*	1041 (377)*	**0.002**
$\dot{V}O_2$ (mL·min^{-1}·kg^{-1})	11.6 (4.0)	13.0 (4.1)*	12.5 (4.3)*	**0.020**

Variables are presented as mean (SD) and analysed with a repeated-measures ANOVA test. * $p < 0.05$ vs. T0; † $p < 0.05$ vs. T1. $^{\$}$ = log transformed. OUES = oxygen uptake efficiency slope; RER = respiratory exchange ratio; T0 = baseline; T1 = post-prehabilitation; T2 = post-Maintenance; $\dot{V}O_2$ = oxygen consumption.

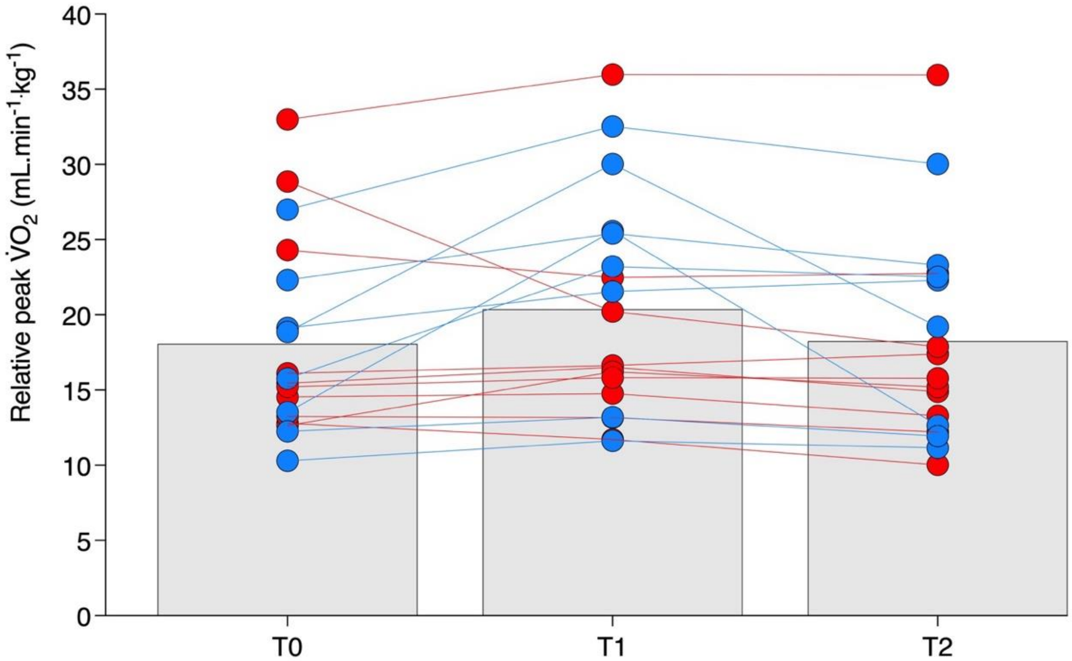

Figure 2. Peak oxygen consumption at baseline (T0), post-prehabilitation (T1) and post-maintenance (T2). Results from individual participants (symbols and lines) and mean (grey bars) are presented for each time point. Red = participant performed supervised heat therapy between T0 and T1; Blue = participant performed supervised HIIT between T0 and T1.

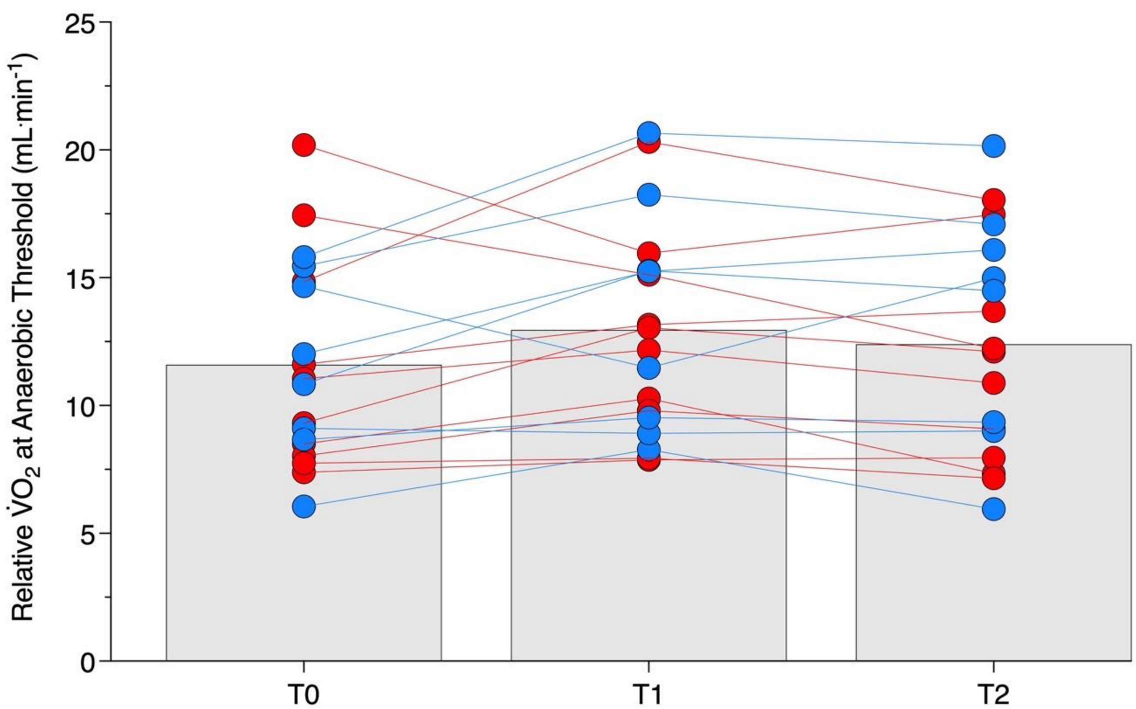

Figure 3. Anaerobic threshold at baseline (T0), post-prehabilitation (T1) and post-Maintenance (T2). Results from individual participants (symbols and lines) and mean (grey bars) are presented for each time point. Red = participant performed supervised heat therapy between T0 and T1; Blue = participant performed supervised HIIT between T0 and T1.

Resting cardiovascular indices

Resting blood pressure and heart rate data are presented in Table 3, Figure 4 and Figure 5. Mean resting systolic blood pressure decreased by 14 mm Hg across T0 to T1 ($p = 0.001$) and although it increased by 5 mm Hg across T1 to T2 ($p = 0.048$), it was still 9 mm Hg lower than T0 ($p = 0.032$). The removal of a large outlier in Figure 4 did not affect the overall statistical significance ($p = 0.016$). Diastolic blood pressure and mean arterial pressure decreased across T0 to T1 (both $p < 0.001$) and remained lower at T2 (vs. T0: $p \leq 0.048$), but was not different to T1 (T1 vs. T2: $p \geq 0.253$).

Table 3. Resting cardiovascular indices at baseline (T0), post-prehabilitation (T1) and post-Maintenance (T2).

Variable	T0	T1	T2	Time effect (p-value)
Resting blood pressure				
Systolic blood pressure (mm Hg)	135 (15)	121 (8)*	126 (9)*†	**< 0.001**
Diastolic blood pressure (mm Hg)	78 (6)	74 (5)*	76 (6)*	**0.005**
Mean arterial pressure (mm Hg)	97 (8)	90 (5)*	93 (5)*	**< 0.001**
Resting heart rate ($b \cdot min^{-1}$)	68 (9)	67 (10)	69 (11)	0.554

Variables are presented as mean (SD) and analysed with repeated-measures ANOVA test. * $p < 0.05$ vs. T0; † $p < 0.05$ vs. T1. T0 = baseline; T1 = post-prehabilitation; T2 = post-maintenance.

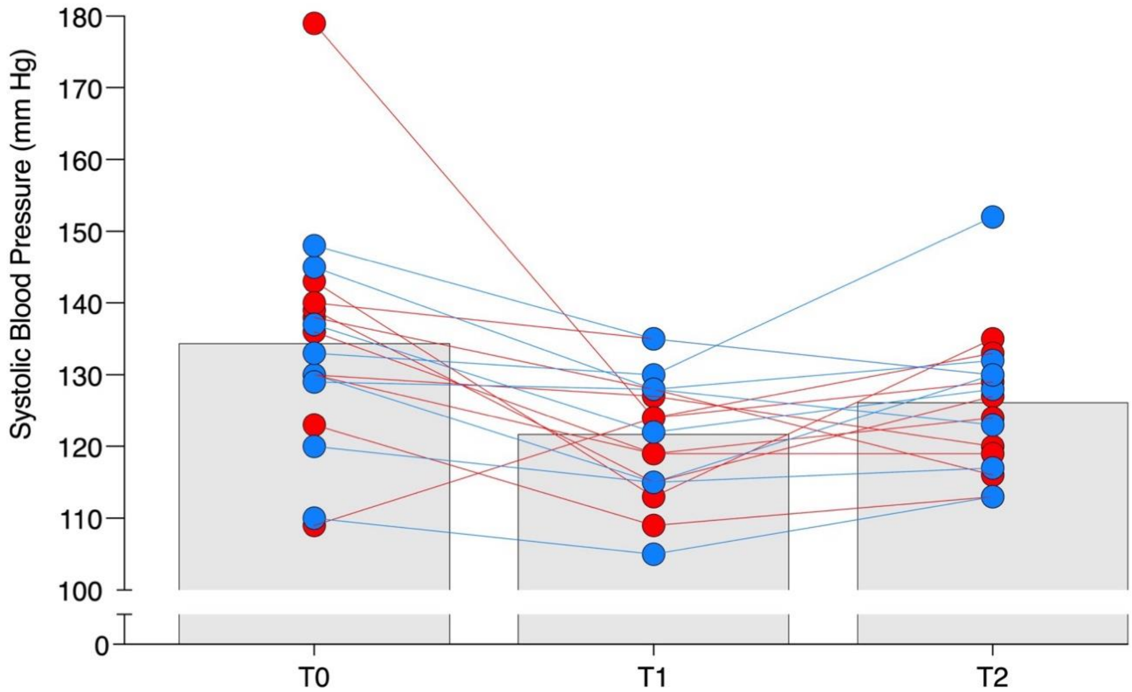

Figure 4. Baseline (T0), post-prehabilitation (T1) and post-maintenance (T2) resting systolic blood pressure. Results from individual participants (symbols and lines) and mean (grey bars) are presented for each time point. Red = participant performed supervised heat therapy between T0 and T1; Blue = participant performed supervised HIIT between T0 and T1.

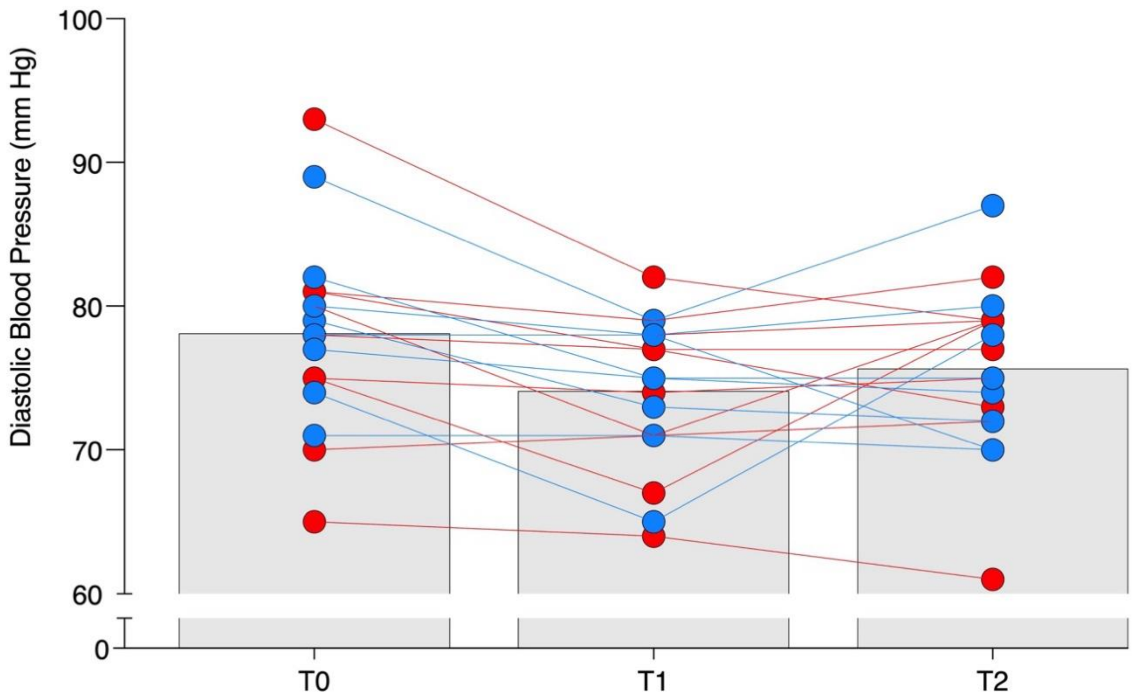

Figure 5. Baseline (T0), post-prehabilitation (T1) and post-maintenance (T2) resting diastolic blood pressure. Results from individual participants (symbols and lines) and mean (grey bars) are presented for each time point. Red = participant performed supervised heat therapy between T0 and T1; Blue = participant performed supervised HIIT between T0 and T1.

Physical function and isometric muscle strength

Measures of physical function and isometric strength are presented in Table 4 and Table 5. For the 30-s sit-to-stand test, participants performed 2 additional reps at T1 ($p = 0.010$) and 1 additional rep at T2 ($p = 0.048$), compared to T0. For the 30-s arm curl test, number of reps did not increase significantly across T0 to T1 ($p = 0.057$), but was 3 reps higher at T2 than T0 ($p = 0.002$). Knee joint range of motion did not show a change on either the scheduled or non-scheduled arthroplasty side ($p \geq 0.870$).

Isometric strength on both the scheduled arthroplasty side and non-scheduled arthroplasty side was mostly unchanged across T1 to T2 (Table 5). However, hip abduction strength increased on the non-scheduled arthroplasty side across T0 to T1 ($p= 0.017$) and had not clearly diminished at T2 ($p = 0.069$).

Anthropometric measures showed no time effect (Table 6).

Table 4. Functional measures and knee range of motion at baseline (T0), post-prehabilitation (T1) and post-maintenance (T2).

Variable	T0	T1	T2	Time effect (p-value)
Functional measures				
Sit-to-stand (reps)	11 (4)	13 (4)*	12 (4)*	**0.036**
TUAG (s)	9.9 (4.1)	8.9 (3.0)	10.2 (3.3)	0.319
Arm curl (reps)	19 (4)	21 (6)	22 (5)*	**0.028**
Knee range of motion				
Scheduled TJA side (°)	115 (15)	115 (15)	116 (15)	0.896
Non-scheduled TJA side (°)	121 (15)	122 (15)	121 (14)	0.870

Variables are presented as mean (SD) and analysed with a repeated-measures ANOVA test. * $p < 0.05$ vs. T0. T0 = baseline; T1 = post-prehabilitation; T2 = post-maintenance. TJA = total joint arthroplasty; TUAG = Timed up-and-go.

Table 5. Isometric muscle strength data at baseline (T0), post-prehabilitation (T1) and post-Maintenance (T2).

Variable	T0	T1	T2	Time effect (p-value)
Scheduled TJA side				
Knee Extension (N)	113 (39)	128 (40)	124 (43)	0.125
Knee Flexion (N)	81 (34)	82 (36)	84 (34)	0.704
Hip Abduction (N)	72 (31)	85 (39)	77 (32)	0.156
Hip Extension (N)	76 (33)	83 (48)	82 (39)	0.655
Non-scheduled TJA side				
Knee Extension (N)	131 (56)	148 (40)	141 (51)	0.213
Knee Flexion (N)	95 (44)	95 (32)	98 (28)	0.888
Hip Abduction (N)	80 (30)	97 (33)*	86 (31)	**0.034**
Hip Extension (N)	84 (40)	92 (46)	81 (26)	0.216

Data are presented as mean (SD) and analysed with a repeated-measures ANOVA test. * $p < 0.05$ vs. T0; TJA = total joint arthroplasty; T0 = baseline; T1 = post-prehabilitation; T2 = post-maintenance.

Table 6. Anthropometric variables at baseline (T0), post-prehabilitation (T1) and post-maintenance (T2).

Variable	T0	T1	T2	Time effect (p-value)
Body mass (kg)	84.8 (14.0)	85.2 (14.3)	85.3 (13.9)	0.228
Skeletal muscle mass (kg)	26.0 (6.4)	27.4 (7.4)	27.4 (6.0)	0.419
Fat-free mass (kg)	47.0 (11.0)	49.4 (12.5)	49.7 (10.0)	0.378
Body fat mass (kg)	37.8 (13.2)	35.8 (12.2)	35.6 (12.0)	0.325
Percent body fat (%)	44.0 (12.4)	41.9 (12.3)	41.2 (10.5)	0.340

Variables are presented as mean (SD) and analysed with a repeated-measures ANOVA test. * $p < 0.05$ vs. T0; T0 = baseline; T1 = post-prehabilitation; T2 = post-maintenance.

Physical activity

Physical activity data from accelerometry are presented in Table 7. No changes were evident in any measure of physical activity across the intervening periods.

Questionnaires

There were no changes in osteoarthritis impact or estimated functional capacity (Table 8). Perceived quality of life (i.e., EQ-5D Score) decreased slightly across T0 to T1 ($p = 0.035$) and this was maintained at T2 ($p = 0.114$).

Table 7. Daily physical activity data at baseline (T0), post-prehabilitation (T1) and post-maintenance (T2).

Variable	T0	T1	T2	Time effect (p-value)
Total steps (n)	5834 (1699)	5427 (1855)	5469 (2180)	0.540
Time spent upright (min)	321 (103)	295 (120)	299 (126)	0.254
Time spent stepping (min)	79 (22)	75 (25)	75 (27)	0.568
Sitting time (min)	581 (91)	615 (92)	587 (127)	0.381
Sit-to-stand transitions (reps)	40 (9)	37 (5)	39 (11)	0.408
Sitting bouts > 30 min (reps)	5 (2)	6 (1)	5 (2)	0.427
Sitting bouts > 60 min (reps)	2 (1)	2 (1)	2 (1)	0.889
Time spent in sitting bouts > 30 min (min)	343 (105)	371 (92)	346 (124)	0.507

Data collected over a 7-day period and presented as daily mean (SD) and analysed with a repeated-measures ANOVA test. * $p < 0.05$ vs. T0. T0 = baseline; T1 = post-prehabilitation; T2 = post-maintenance.

Table 8. Patient reported outcome measures at baseline (T0), post-prehabilitation (T1) and post-Maintenance (T2).

Variable	T0	T1	T2	Time effect (p-value)
WOMAC				
Overall score	55 (16)	59 (14)	58 (17)	0.268
Pain	11 (3)	12 (4)	12 (3)	0.235
Stiffness	5 (2)	5 (2)	5 (1)	0.513
Physical function	39 (12)	41 (13)	42 (11)	0.473
OHS / OKS	17 (8)	16 (6)	16 (7)	0.385
OHS	19 (11)	16 (6)	13 (8)	0.390
OKS	17 (7)	17 (7)	17 (6)	0.815
EQ-5D				
Health today	61 (28)	64 (24)	63 (20)	0.684
Quality of life	13 (2)	14 (3)*	14 (4)	**0.040**
SF12				
PCS	30 (9)	29 (5)	28 (5)	0.502
MCS	49 (12)	48 (11)	47 (9)	0.764
DASI				
Score	18 (9)	17 (6)	17 (7)	0.613
Estimated peak $\dot{V}O_2$ (mL·min^{-1}·kg^{-1})	17.4 (4.0)	16.9 (2.6)	16.8 (3.2)	0.611

Data presented as mean (SD) and analysed with a repeated-measures ANOVA test. * $p < 0.05$ vs. T0; DASI = Duke activity status index (0 worst – 58 best); EQ5D = European Quality of Life Five Dimension; EQ-5D Health today (0 worst – 100 best); EQ-5D Quality of life (5 best – 25 worst); MCS = Mental health component score; OHS / OKS = Oxford hip score / Oxford knee score (0 worst – 48 best); PCS = Physical health component score; T0 = baseline; T1 = post-prehabilitation; T2 = post-Maintenance; WOMAC = Western Ontario and McMaster Universities Osteoarthritis Index (0 best – 94 worst).

Discussion

The purpose of this study was to examine the effect of a home-based intervention for maintaining cardiorespiratory fitness after supervised prehabilitation in patients with severe lower-limb osteoarthritis scheduled for total joint arthroplasty. Increases in peak $\dot{V}O_2$ from supervised prehabilitation were lost across the maintenance intervention. However, increases in anaerobic threshold, that exceeded prognostic surgical cut-offs, were largely preserved across the maintenance intervention. Maintenance was effective also for preserving the hypotensive effect of the supervised prehabilitation. Lastly, the maintenance intervention did not worsen the subjective impact (e.g., symptoms) of osteoarthritis.

Was the home-based maintenance intervention effective for maintaining cardiorespiratory fitness after supervised prehabilitation?

Peak $\dot{V}O_2$

Peak $\dot{V}O_2$ increased across supervised prehabilitation (i.e., T1), however it decreased across maintenance and at T2 was not different from baseline. This implies that home-based maintenance was not effective for maintaining gains in peak $\dot{V}O_2$ achieved during the supervised intervention. However, a positive interpretation is that the maintenance intervention at least prevented decreases in peak $\dot{V}O_2$ below baseline during surgical waitlisting, which could be anticipated due to the natural decline in aerobic fitness in this population [31].

Previous research for comparison is limited. However, following supervised cardiac rehabilitation, maintenance of peak $\dot{V}O_2$ in an unsupervised setting is possible. Izawa et al. [9] recruited 16 patients following supervised cardiac rehabilitation and showed home-based walking and body-weight exercise was effective for maintaining peak $\dot{V}O_2$ (30.2 ±7.8 to 30.8 ± 6.6 $mL \cdot min^{-1} \cdot kg^{-1}$) over 6 months. In the current study, despite orthopaedic limitations, participants on average increased their daily step count by the required 10% in the first four weeks, but managed only 5% and 7% increases thereafter. Although the amount of activity increased, albeit not to the targeted amount, it remains unknown whether intensity increased as this could not be measured via the pedometer; this lack of intensity and/or limited volume progression may explain the failure to maintain the supervised-training-mediated increase in peak $\dot{V}O_2$.

A challenge with any home-based exercise intervention is achieving a sufficient exercise intensity without the security and motivation that comes with supervision. The approach utilised here with a prior supervised prehabilitation programme may have gone some way to alleviating this problem, building skills and confidence for the participants prior to initiating the home-based programme. Nevertheless, maintenance of intensity appears to be the necessary stimulus for maintaining training adaptations when volume is decreased [32,33]; unfortunately, it was not feasible for participants who completed the HIIT arm of the supervised prehabilitation study to maintain this intensity in an unsupervised setting mainly due to logistical limitations. Participants who were exercising using equipment during maintenance (*n*=3) were on average exercising at an intensity of 5/10 (i.e., "hard"); as stated in the previous paragraph, no intensity data are available from the participants using the pedometer. Therefore, the decrease in peak $\dot{V}O_2$ during the maintenance phase may be explained in part by the reduction of stimulus intensity for approximately half the sample (i.e., participants from the HIIT training intervention). Other external factors such as lack of supervision, commitment to attend and reduced motivation with the extended waiting period may have also played a role.

Anaerobic threshold

Although increases in peak $\dot{V}O_2$ were not maintained across the maintenance intervention, increases in the anaerobic threshold were. This is clinically important as an anaerobic threshold < 11 $mL \cdot min^{-1} \cdot kg^{-1}$ (~1.0 $L \cdot min^{-1}$) is associated with increased surgical risk [3] and poorer functional and subjective recovery 6-wk post-arthroplasty. Importantly, supervised prehabilitation increased anaerobic threshold above this prognostic cut-off, and it was maintained following the maintenance intervention. Similarly, Butler and co-workers [10] demonstrated *increased* anaerobic threshold in cardiac rehabilitation graduates using a home-based pedometer intervention; the authors did not present peak $\dot{V}O_2$ data, but the anaerobic threshold increased by 10% across the 6-month intervention [10].

It is unclear why the anaerobic threshold was maintained, whilst peak $\dot{V}O_2$ decreased. There is a belief that the anaerobic threshold may be more responsive to low- or moderate-intensity exercise (than peak $\dot{V}O_2$) [34]; thus the regularity and lower-intensity nature of the home-based programme was effective for maintaining the anaerobic threshold (but not peak $\dot{V}O_2$). It is also possible that training adaptations were actually maintained with the maintenance intervention and as the anaerobic threshold is less influenced by subjective factors (e.g., joint pain, lack of effort), this was captured.

Was the home-based maintenance intervention effective for maintaining other measures of physical and subjective health after supervised prehabilitation?

Resting blood pressure

The maintenance intervention was effective for maintaining the hypotensive effect of the prior supervised prehabilitation. As little as two weeks of detraining is sufficient to reverse the hypotensive benefits achieved from a prior six-month exercise intervention [35], so the effectiveness of this maintenance intervention at preserving the blood pressure reduction is important and encouraging.

Physical function

The performance of the 30-second sit-to stand increased by 2 reps across supervised prehabilitation (T0-T1), however this gain in strength-endurance was lost during the maintenance intervention (T1-T2); similarly so for hip abduction as an indicator of isometric strength. As there was a trend for skeletal muscle mass to be higher post-maintenance compared to baseline, this strength loss is unlikely the result of atrophy although neurological strength losses may have occurred. Furthermore, it is plausible that deterioration in the osteoarthritic joint contributed to the lower post-maintenance scores, rather than reduced muscle strength *per se*.

Physical activity

Despite the presence of lower-limb osteoarthritis, the pedometer-based intervention was effective for increasing physical activity. Participants that used a pedometer increased their daily step count by 24% across the maintenance intervention (~5300 to ~6600 steps/day), but below the 30% target. This is similar to Talbot et al. [24], who reported on 34 individuals with knee osteoarthritis. Those randomised to a pedometer-based intervention increased their daily step count by 23%, whilst a 15% decrease was observed in the group that received education alone. Again, a positive interpretation might be that the maintenance intervention promoted increased physical activity in a population who would otherwise likely do less.

Interestingly, when comparing objectively-measured step count at the end of supervised prehabilitation (T1) and post-maintenance (T2) there was no difference in step count (~5450 steps/day for both). Participants may have been over-reporting their steps during the intervention, or they may have reverted back to their prior activity levels immediately once the pedometer was returned.

Patient reported outcome measures

There was no deterioration in subjective impact of osteoarthritis across the maintenance intervention; reassuring in this setting of severe osteoarthritis, which might be expected to worsen over this time frame. There was a trend downwards on the Oxford hip scale across all time points and this may be associated with greater severity and more rapid progression of hip osteoarthritis compared to knee osteoarthritis [36]. There were no clinically significant improvements in perceived quality of life (EQ-5D score).

Limitations

Several limitations warrant acknowledgement. A convenience sample of participants who had completed a larger study, but not yet had their surgery scheduled was chosen [11]; therefore this study may be underpowered. The lack of a control group limits inferences to be made from the data. However, as participants had invested significant time and effort to make positive improvements during supervised prehabilitation, it could be considered unethical to then provide no advice and support to help maintain this progress till surgery. This is pertinent as we previously showed that patients not performing aerobic-based exercise before hip or knee arthroplasty have decreases in peak $\dot{V}O_2$ [11].

Participants were required to self-report their adherence to the intervention, which has inherent limitations [37]. However, the average pedometer daily step count in week one of maintenance was very similar to accelerometry data from post-supervised prehabilitation (~5300 vs. ~5400 steps/day), suggesting that overall the pedometer provided reliable readings and self-reporting was reliable. It should also be noted that although participants in the pedometer intervention increased daily step count by 24% across 12 wk, it was less than the 30% target.
Not all participants performed supervised *exercise* prehabilitation prior to the maintenance intervention. It is possible that those who had performed hot-water immersion prior to maintenance (n=10) did not receive the same level of education and behaviour change support to be physically active, as those who had completed HIIT (n=8).

Conclusion

This study demonstrated that the home-based maintenance intervention was effective at maintaining the anaerobic threshold above surgical prognostic cut-offs (this had been improved in prior 12-wk supervised prehabilitation programme). However, the maintenance intervention was not effective for maintaining the improvements achieved in peak $\dot{V}O_2$. Decreases in resting blood pressure were maintained, and subjective impact of the osteoarthritis did not deteriorate. Lastly, physical activity increased, and this was achieved in a manner that can be done conveniently (at home, on participant's own schedule, requiring no transportation or specialised equipment). This study provides preliminary evidence for maintaining some fitness and health measures using a relatively low-cost and safe delivery of prehabilitation. Future work is needed to optimise the efficacy of the intervention, and to evaluate if these effects translate to improved surgical outcomes.

Acknowledgements
The authors would like to thank all participants for the time and effort associated with study participation.

Author contributions
Study conception and design: BR, JC & KT. *Data collection, analysis and interpretation*: BR, HC, MJAW, JC & KT. *Drafting of original manuscript*: BR & KT. *Critical revisions of the work for important intellectual content*: BR, JC, HC, UR, DGJ, MJAW & KT. *Final approval*: BR, JC, HC, UR, DGJ, MJAW & KT.

Funding
This study was funded by the Health Research Council of New Zealand (grant number: 18/636 (KT)) and a Health Research South Start-Up Award, University of Otago (KT). BR was supported by a University of Otago Doctoral Scholarship. These funders had no role in the study design, data collection, analysis, or interpretation; drafting the manuscript; or the decision to submit the manuscript for publication.

Disclosures
No conflicts of interest, financial or otherwise, are declared by the authors.

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