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Impact of prehabilitation on objectively measured physical activity levels in elective surgery patients: a systematic review

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ABSTRACT

Objective To systematically review the impact of prehabilitation on objectively measured physical activity (PA) levels in elective surgery patients.

Data sources Articles published in Web of Science Core Collections, PubMed, Embase (Ovid), CINAHL (EBSCOHost), PsycInfo (EBSCOHost) and CENTRAL through August 2020.

Study selection Studies that met the following criteria: (1) written in English, (2) quantitatively described the effect(s) of a PA intervention among elective surgery patients prior to surgery and (3) used and reported objective measures of PA in the study.

Data extraction and synthesis Participant characteristics, intervention details, PA measurement, and clinical and health-related outcomes were extracted. Risk of bias was assessed following the revised Cochrane risk of bias tool. Meta-analysis was not possible due to heterogeneity, therefore narrative synthesis was used.

Results 6533 unique articles were identified in the search; 21 articles (based on 15 trials) were included in the review. There was little evidence to suggest that prehabilitation is associated with increases in objectively measured PA, but this may be due to insufficient statistical power as most (n=8) trials included in the review were small feasibility/pilot studies. Where studies tested associations between objectively measured PA during the intervention period and health-related outcomes, significant beneficial associations were reported. Limitations in the evidence base precluded any assessment via meta-regression of the association between objectively measured PA and clinical or health-related outcomes.

Conclusions Additional large-scale studies are needed, with clear and consistent reporting of objective measures including accelerometry variables and outcome variables, to improve our understanding of the impact of changes in PA prior to surgery on surgical and health-related outcomes.

PROSPERO registration number CRD42019151475.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ This review is the first to synthesise the findings of prehabilitation interventions in which objective measurements of physical activity were used.
⇒ A systematic approach was used and evidence across surgery types was included.
⇒ Meta-analysis and meta-regression were not possible due to heterogeneity in measurements and reporting conventions.

INTRODUCTION

Preoperative levels of physical fitness have been positively associated with surgical outcomes, including lower risk of postoperative morbidity and mortality.[1–3] This may be because preoperative physical fitness is indicative of the body's capacity to withstand the stress of surgery,[3] which may in turn contribute to a faster recovery from surgery and a quicker return to preoperative physical functioning levels. As postoperative morbidity is a substantial burden on health systems and can have adverse impacts on patients' health and well-being,[4] interventions to reduce the risk of poor postoperative outcomes are important.

In recent years, exercise interventions prior to surgery ('prehabilitation') have become increasingly recognised as a way to improve surgical outcomes across surgery types.[5 6] There is diversity in prehabilitation programme methods and contents (eg, supervised exercise training, home-based physical activity (PA) programmes, educational sessions), but all share the key goal of improving patients' functional capacity in advance of surgery in order to improve clinical outcomes following surgery.[7 8] Across surgery types, a number of systematic reviews and meta-analyses have concluded that prehabilitation is effective for increasing patients' functional capacity,[9] reducing patients' length of hospital stay[10–12] and reducing the likelihood of postoperative complications.[11–16]

A key element that has received little attention within the context of prehabilitation is

the use of objective measures of PA such as accelerometry. Accelerometers capture free-living movement of all intensities, usually over a week-long period, and can be used to estimate time spent in moderate-to-vigorous physical activity (MVPA) or light-intensity PA, average daily acceleration or average steps per day.[17 18] While there is some variation in the validity of accelerometer measurements (driven largely by variation in wear protocol specifications), accelerometers have been shown to have near-perfect agreement with direct observation for the classification of PA intensity[19–22] and have higher measurement validity than subjective methods.[22] To date, most prehabilitation interventions have used self-report methods to estimate changes in PA levels across the intervention period.[23–25] However, self-reported measures of PA are not well-suited to capturing changes in PA levels over time[26] and the high measurement error of self-report methods for estimating total PA severely limits the interpretability of the findings. Use of accelerometry within the context of prehabilitation could overcome these limitations, enabling stronger estimates of the impact that prehabilitation may have on PA levels prior to surgery and the subsequent impact on clinical outcomes. The extent to which accelerometry has been used in prehabilitation interventions is not currently known.

This review seeks to synthesise the available literature that has used objective (ie, device-based) measures of PA within the context of prehabilitation. The specific aims of this systematic review are (1) to assess the impact of prehabilitation interventions on objectively measured PA levels and (2) to determine meta-associations between objectively measured PA levels during the prehabilitation period on health-related and clinical outcomes.

METHODS

Information sources and search strategy

The protocol for this review was registered with PROSPERO. Six databases (Web of Science Core Collections, PubMed, Embase (Ovid), CINAHL (EBSCOHost), PsycInfo (EBSCOHost), Central) were systematically searched in August 2020 using broad search terms to capture exercise interventions related to surgery (online supplemental file 1). The search was not limited by publication date but was restricted to publications written in English. The citations of included articles were checked and, if relevant, were included in the review.

Eligibility criteria

Studies were included in the review if they (1) quantitatively described the effect(s) of a PA intervention among elective surgery patients prior to surgery and (2) used and reported objective measures of PA in the study. There were no limits to the kind of surgery for which patients were scheduled, nor were there restrictions on the prehabilitation programme contents or structure. Exclusion criteria included (1) no reported objective measures of PA and (2) observational studies in which no PA interventions were implemented.

Study selection and data extraction

Titles and abstracts of the search results were screened for relevance. A subsample (10%) was screened independently by two reviewers (JW and Dr Sonia Ahmed) for eligibility to check consistency and agreement (which was high, 97%) before the lead author continued with the remainder of the screening. The full texts for any articles with relevant abstracts were consulted for eligibility.

Eligible studies were read and their data were extracted by the lead author using a prespecified data extraction form adapted from Booth *et al*[27] including general study details, study design and methodology, sample characteristics, statistical analyses and main study findings. Risk of bias was assessed by the lead author (JW) following the revised Cochrane risk of bias tool (RoB 2).[28] A second author (AK) independently assessed the risk of bias for a subsample (20%) of articles; agreement between both authors' assessments was high. Risk of bias was done for each article (even where multiple articles reported on the same trial) because outcome variables and prevalence of missing data differed between articles and thus required separate consideration.

Synthesis of results

Because of lack of data and inconsistencies in the ways in which outcome data were reported, meta-analysis was not possible. A narrative synthesis was used instead to summarise the review findings. Throughout the narrative, we present the findings in order of study rigour, primarily in terms of study design, for example, randomised controlled trials (RCTs) first. We also discuss changes specific to the intervention period (ie, preintervention and postintervention) first before discussing any measurements gathered from the follow-up period.

Patient and public involvement

No patients involved.

RESULTS

Study selection and characteristics

The flow of studies through the review is shown in figure 1. After the removal of duplicates, 6533 unique articles were screened. In many cases, it was not immediately clear from the title and abstract of relevant articles whether PA was measured objectively, thus the full-text was consulted for a large number of articles.

Twenty-one articles reporting on 15 separate trials were eligible for inclusion in the review (table 1). Over half (n=8) of the trials identified themselves as feasibility or pilot studies. The majority of trials (n=9) were based in Europe (n=4 of these in the UK) with the remainder (n=6) based in North America (n=3 in the USA, n=3 in Canada). Nine trials were RCTs with sample sizes ranging from 17 to 118; five were single-arm trials with sample sizes ranging from

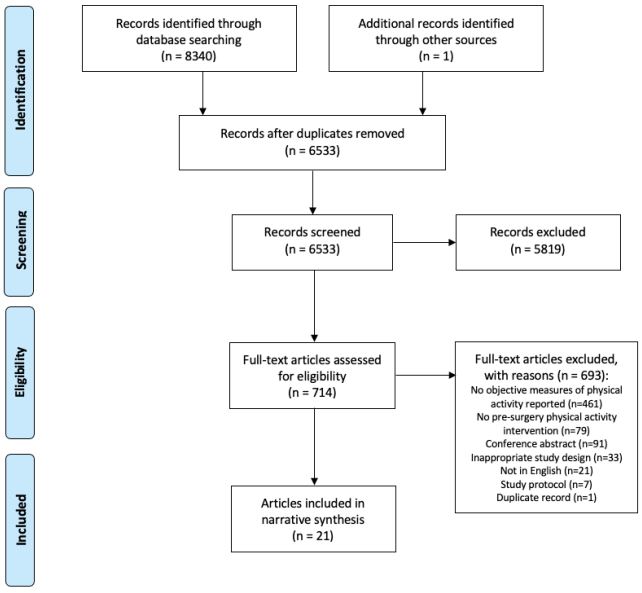

Figure 1 Flow of studies through the review.

12 to 50 and one was a non-randomised parallel group trial (n=35). Most of the trials (n=7) involved patients preparing for cancer-related surgery; the remainder were patients preparing for bariatric surgery (n=2), kidney or liver transplantation (n=2), orthopaedic surgeries (n=2), coronary artery bypass grafting (n=1) or general major surgery (n=1).

The prehabilitation interventions were highly variable and diverse in terms of duration and content (table 2). In 11 of the trials, the interventions consisted of structured exercise training programmes that involved either supervised training sessions in a facility (n=6) or unsupervised home-based programmes (n=5). In four trials, the interventions consisted of education-based or behavioural change programmes in which patients were given advice or counselling regarding PA but were not given a detailed programme to follow. One study used both exercise training and education within the intervention.[29] The duration of the interventions ranged from a one-off information session to a structured and supervised 3-month to 6-month programme while patients awaited bariatric surgery.

The measurements of PA used in each trial are described in tables 3 and 4. Ten trials objectively measured PA during the intervention period (table 3) and seven trials objectively measured PA postoperation (table 4); two trials measured PA at both time points and are thus counted two times here. The most common type of accelerometer used was the Actigraph (n=6 trials) and the most common wear protocol (regardless of accelerometer brand) was hip-worn (n=6) followed by wrist-worn (n=4). Daily steps were the most frequently measured metric of PA (n=9) followed by indices of overall PA (eg, mean counts per minute, total active minutes; n=7) and time spent in MVPA (n=6), although the definitions of MVPA varied between trials. Most trials measured more than one metric, for example, three trials measured both steps per day and time spent in MVPA.

Impact of prehabilitation on PA levels

Eight trials reported on changes in objectively measured PA from baseline to postintervention[29–35] or the end of the intervention period[36 37] (table 3). Among RCTs or non-randomised parallel group trials (n=4), only one study reported a significant difference: Bond *et al*[31] reported a significantly larger improvement in MVPA and steps per day in the intervention group compared with the control group from baseline to postintervention. The remaining RCTs/parallel studies reported no differences between intervention and control groups in objectively measured total PA level[29 34 36] or steps per day[29 34 36 37] from baseline to postintervention[29 34] or baseline to the end of the intervention.[36 37] Single-arm trials tended to report significant increases in PA across the intervention period. Grimes *et al*[32] and McAdams-DeMarco *et al*[33] reported significant increases in objectively measured total PA from baseline to the end of the intervention and Williams *et al*[35] reported a significant increase in steps per day. Alejo *et al*[30] found no difference in MVPA from baseline to the end of the intervention.

Seven trials (all RCTs) compared objectively measured PA levels in terms of total PA, time in MVPA and light physical activity (LPA), and steps per day between the intervention and control groups in the postoperative period, ranging from postoperative day 1 to 1 year following surgery[29 38–43] (table 4). Four trials made cross-sectional comparisons between the PA levels of the intervention group and control group in the postoperative period, and all four studies found significant differences.[38–41] Three of these reported that PA levels were higher among the prehabilitation group in terms of total PA on postoperative day 1,[38] steps per day at 6 months[40] and steps per day 1 year[39] following surgery; the fourth study found that the prehabilitation group had fewer steps per day than the control group in the immediate postoperative period.[41] The remaining three trials compared changes in PA levels from baseline to the postoperative period (3 months) and found no significant differences in change in MVPA,[42 43] total PA,[29 43] steps per day,[29 42] light PA[42] or sedentary time[42] between the intervention and control groups in the postoperative period.

Impact of objectively measured PA on health-related outcomes

Four trials tested associations between changes in objectively measured PA over the intervention period and health- and clinically-related outcomes.[44–47] Bond *et al*[44] reported that increases in MVPA (accumulated in bouts lasting ≥10 min) during the intervention period were associated with significant improvements in health-related quality of life in terms of physical function (β=0.43, p=0.04), bodily pain (β=0.39, p=0.03) and general health (β=0.56, p=0.048) (no CIs were reported). Among the same sample, increases in MVPA were not associated

Table 1 General study characteristics

Study	Location	Study design	Surgery type	Intervention arm n	Control arm n	Intervention arm age	Control arm age
Alejo *et al*[30]	Spain	Single-arm	Surgery for rectal cancer following NACRT	12	N/A	61±7	N/A
Au *et al*[38]	Canada	RCT	Radical prostatectomy	19	19	61.4±7.8	58.4±6.1
Baillot *et al*[39]	Canada	RCT	Bariatric surgery	13	12	44.5±8.8	41.1±10.3
Bond *et al*[31 44 45]	USA	RCT	Bariatric surgery	40	35	44.2±9.2	48.1±8.1
Bond *et al*[40]				22	14	46.4±9.1	47.9±6.8
Dronkers *et al*[46]	The Netherlands	RCT	Elective abdominal oncological surgery	22	20	71.1±6.3	68.8±6.4
Grimes *et al*[32]	UK	Single-arm	High-risk surgery among elderly patients (including orthopaedic, gastrointestinal, urological, vascular, gynaecological and breast surgeries)	35	N/A	79.9±5.6	N/A
Guinan *et al*[41]	Ireland	RCT	Oesophagectomy	28	32	63.1±8.8	65.1±67.8
Huber *et al*[29]	Switzerland	RCT	Total knee replacement	22	23	68.8±8.0	71.9±8.1
Lotzke *et al*[42]	Sweden	RCT	Lumbar fusion surgery	59	59	44.8±8.2	46.7±8.5
Loughney *et al*[36] West *et al*[37]	UK	Non-randomised parallel group	Surgery for rectal cancer	23	10	64 (range 45–82)	72 (range 62–84)
				22	13	64 (range 45–82)	72 (range 62–84)
McAdams-DeMarco *et al*[33]	USA	Single-arm	Kidney transplantation	18	N/A	52±12.9	N/A
Moug *et al*[34] Moug *et al*[51]	UK	RCT	Surgery for rectal cancer with NACRT	24	24	65.2±11.4	66.5±9.6
				20	24	66.8±9.6 (both arms combined)	
Ngo-Huang *et al*[47] and Parker *et al*[52]	USA	Single-arm	Pancreatectomy	50	N/A	66±8	N/A
Sawatzky *et al*[43]	Canada	RCT	Elective coronary artery bypass graft	8	9	64±7	63±9
Williams *et al*[35]	UK	Single-arm	Liver transplantation	18	N/A	Median 55 (IQR 44–63)	N/A

NACRT, neoadjuvant chemoradiotherapy; RCT, randomised controlled trial.

with changes in enjoyment, self-efficacy or motivation for PA (only p values were reported, ranging from 0.20 to 0.90).[45] Dronkers *et al*[46] reported a significant correlation (r_{pb}=0.50, p=0.02; no CIs reported) such that those with more objectively measured steps per day during the intervention period were less likely to experience postoperative pulmonary complications. In a single-arm trial, Ngo-Huang *et al*[47] reported that accelerometer-measured MVPA and LPA averaged over the prehabilitation period were each associated with improvement in 6 min walk test

Table 2 Prehabilitation programme characteristics

Study	Type of programme	Frequency and duration of sessions	Programme contents	Adherence and adverse events (AEs)	Control arm
Alejo *et al*[30]	Education	35–60 min, 6 sessions over 5 weeks	Theoretical education sessions (n=1) discussing the benefits and risks of exercise as well as practical sessions (n=5) demonstrating various exercises and intensities	10 of 12 participants completed all sessions; 89% of sessions were completed. No reported AEs	N/A
Au *et al*[38]	Unsupervised home-based exercise training	N/A, 4–8 weeks	Moderate-intensity aerobic and resistance exercises were prescribed after patients consented to surgery, and participants were provided with exercise bands, mats, stability ball and manual detailing their prescription. Coaching on pelvic floor exercises was also provided	Not reported	Received same pelvic floor exercise coaching as the prehab group and a book on maintaining a healthy lifestyle following prostate cancer diagnosis with no further exercise support
Baillot *et al*[39]	Supervised exercise training at hospital/clinic	Three 80 min sessions per week, plus individual PA and nutrition counselling every 6–8 weeks before surgery and at 3, 6, 9 and 12 months after surgery Mean 32.6±8.0 weeks (range 27–51 weeks)	Exercise sessions included 30 min of endurance activity at 55%–85% of heart rate reserve (treadmill, elliptical, arm-ergocycle, walking circuit, dance/aerobic exercise) and 20–30 min of strength exercises (dumbbells, elastic bands, medicine balls, sticks) with 10 min warmup and cooldown on either side	Median of 70% of total recommended sessions were attended. Seven participants (47%) attended more than 70% of sessions	Received the same individual PA and nutrition counselling before and after surgery as the intervention group
Bond *et al*[31 40 44 45]	Home-based behavioural/activity intervention	Six weekly face-to-face counselling sessions lasting 30–45 min	During counselling sessions, the importance of PA was discussed, a preoperative walking programme was established, and problem-solving and goal-setting were discussed. The aims of the intervention were to increase bouted MVPA by 30 min/day (via moderate intensity walking) and to increase steps by 5000/day. Participants were given logs and pedometers to track and motivate progress toward their goals, reviewed at their weekly sessions	33 of the 40 participants assigned to the intervention completed the intervention (83%). Of those 33 who completed, 100% attended all 6 weekly sessions	Attended routine preoperative clinic without PA intervention. Participants were advised by surgical team to adopt an active lifestyle and engage in walking and other forms of exercise but with no formal prescription or strategies to change PA

Continued

Table 2 Continued

Study	Type of programme	Frequency and duration of sessions	Programme contents	Adherence and adverse events (AEs)	Control arm
Dronkers *et al*[46]	Supervised exercise programme (hospital-based and home-based)	60 min sessions two times per week for 2–4 weeks	Each session included a warm-up, resistance training of lower limb extensors, inspiratory muscle training, aerobic training for 20–30 min at 55%–75% of maximal heart rate, functional activities according to interest and capability, and cool down. Participants were told to walk or cycle for a minimum of 30 min a day between training sessions and were given a pedometer to monitor this	Attendance at training sessions was 97% in the intervention group. No AEs reported during outpatient or home-based training	Given home-based exercise advice and encouraged to attain 30 min of PA per day in the preoperative period. They received a pedometer to record their activity
Grimes *et al*[32]	Home-based education	One preoperative clinic session	As part of usual preoperative care, participants were given verbal and written advice in the form of generic leaflets and bespoke exercise programmes with the aim to improve their PA through activities of daily living or leisure activities	Not assessed	N/A
Guinan *et al*[41]	Unsupervised home-based inspiratory muscle training (IMT) programme	One face-to-face instructional session with weekly telephone calls from the guiding physiotherapist over ≥2 weeks	Following a face-to-face instructional session, participants completed IMT involving 30 breaths two times per day using a tapered flow resistive inspiratory loading device, beginning at 60% of baseline maximal inspiratory pressure and progressing by 5% when patient-reported perceived exertion was below 7	785/1232 (64%) of prescribed training sessions were completed. 14 participants completed at least 80% of sessions and 5 completed no sessions. No AEs	Standard pathway of surgical preparation care
Huber *et al*[29]	Education and supervised hospital/clinic exercise programme	Education: weekly sessions for 3 weeks Exercise: minimum of 8 sessions over 4–12 weeks	Knee school was taught over three weekly sessions, including information about knee anatomy, recommended activities and postoperative pain management. Neuromuscular training sessions involved a 10 min warmup, four-exercise circuit programme (including stability/postural function, functional alignment, lower-extremity muscle strength and functional exercises) and 10 min cool-down	76.2% attended the predefined goal of 8 or more treatment sessions. One patient missed 2 sessions due to increased pain determined to be an AE	Attended knee school (in separate sessions from the intervention group so as to avoid contamination) but did not receive the neuromuscular training component

Continued

Table 2 Continued

Study	Type of programme	Frequency and duration of sessions	Programme contents	Adherence and adverse events (AEs)	Control arm
Lotzke *et al*[42]	Behavioural intervention at hospital/clinic	Four 1-hour counselling sessions before surgery and 1 half-hour session by telephone 2 weeks after surgery, 8 weeks	Participants met with a physiotherapist to increase participants' knowledge of PA and associated motivations, ability to stay active despite pain, to enhance self-efficacy and to set goals for functioning following surgery	No AEs reported	Conventional care: participants were advised to contact a physiotherapist through which the patient would receive information about postoperative mobilisation and an exercise programme to be initiated the day after surgery or before
Loughney *et al*[36] and West *et al*[37]	Supervised exercise training at hospital	Three 40 min sessions per week for 6 weeks	Training sessions consisted of 40 min of interval training on cycle ergometer alternating moderate (80% of work rate at VO_2 at lactate threshold) to severe (50% of the difference in work rates between VO_2 at peak and lactate threshold). The training programme was modified for each individual's ramped cardiopulmonary exercise test results to ensure consistent and individualised intensity	Mean % adherence to the exercise programme (percentage of the 18 sessions completed) was 96%±5%. No AEs	Standard care with no formal exercise intervention (those who were unable to commit to the exercise training arm were asked to act as contemporaneous controls)
McAdams-DeMarco *et al*[33]	Supervised exercise training at hospital/clinic	Weekly 40 min sessions for 2 months	Following a 1-hour baseline assessment by a physiotherapist, weekly sessions included diaphragmatic breathing exercises, stretching and strengthening with and without elastic stretch bands, Swiss ball exercises for core stability, trampoline exercises for motor skills, balance and coordination, low-impact cardiovascular exercises, strength training with weights, and aerobic exercises using treadmills, exercise bikes and elliptical trainers. Participants were also asked to take part in daily at-home exercises between sessions	8 participants (44%) attended fewer than 4 sessions, 4 (22%) attended between 4 and 12 sessions, and 6 (33%) attended 12 or more sessions. No AEs or safety concerns reported	N/A

Continued

Table 2 Continued

Study	Type of programme	Frequency and duration of sessions	Programme contents	Adherence and adverse events (AEs)	Control arm
Moug *et al*[34 51]	Unsupervised home-based walking programme	One in-person introductory session followed by telephone calls at weeks 1, 3, 5, 7, 9, 12, 16; 13–17 weeks in total	Following an in-person consultation, the walking programme started (prior to NACRT) based on targeted step counts with graduated goals in the first 8 weeks and maintenance over the remaining weeks until surgery. Participants were given a weekly diary and a pedometer to track progress and received follow-up telephone calls at weeks 1, 3, 5, 7, 9, 12 and 16 where new targets were set and any issues were discussed. The overall target was to increase participants' steps by 3000 per day by week 8 compared with their baseline value	80% of planned telephone calls were completed and 75% of participants in the intervention group completed it. No serious AEs reported and no treatment pathways were modified due to trial participation	Standard care with no contact from trial team except at the two test sessions. They were told to maintain their normal level of PA and were offered a voluntary exercise counselling session and information from the trial team after their surgery and on completion of the trial
Ngo-Huang *et al*[47] and Parker *et al*[52]	Unsupervised home-based exercise programme	In-person demonstrations of exercises at enrolment followed by telephone calls every 2 weeks, mean 16 weeks (SD=9)	Participants were advised to take part in ≥60 min of moderate-intensity aerobic exercise per week (eg, brisk walking, elliptical trainer, stationary bicycle) and ≥60 min of full-body strengthening exercises per week. Participants also received nutrition recommendations from a dietitian	42 (84%) participants submitted exercise logs for an average of 66±39% of programme days. No AEs were reported	N/A
Sawatzky *et al*[43]	Supervised exercise programme at medical fitness facility	Two 60 min sessions per week plus 12 education sessions until surgery or for the duration of the 16-week programme (mean 8.2±2.2 weeks)	Exercises were prescribed at 85% of maximal VO_2, and intensity and duration of the exercise progressed throughout the programme. Prescribed exercises were based on individual interests and abilities, including walking, stationary cycling, light resistance exercises and stretching. Participants also attended voluntary exercise sessions at the facility and 12 education sessions about medication use, exercise, stress, diet and cardiovascular risk factor management	No AEs occurred during participation in the intervention	Standard care, including a 3-hour cardiac preassessment meeting in which patients' cardiac status was assessed and counselling on healthy lifestyle behaviours was delivered

Continued

Table 2 Continued

Study	Type of programme	Frequency and duration of sessions	Programme contents	Adherence and adverse events (AEs)	Control arm
Williams *et al*[35]	Unsupervised home-based exercise programme	Weekly 20 min telephone calls for the first 6 weeks, followed by no telephone support in weeks 6–12, 12 weeks total	Participants were given daily step targets based on their baseline daily steps and were given an accelerometer (with step counter) to track their progress. Step targets increased incrementally based on the previous week's target. They were also asked to complete resistance exercises (eg, squats, lunges, bear crawls, rock press) two times per week	Adherence was 82% and 90% for step targets and two times-weekly resistance exercises, respectively, in first 6 weeks, decreasing to 53% and 78% for steps and resistance exercises, respectively. No AEs related to the intervention	N/A

MVPA, moderate-to-vigorous physical activity; NACRT, neoadjuvant chemoradiotherapy; PA, physical activity; VO_2, oxygen consumption.

distance (MVPA β=0.18, p=0.03; LPA β=0.08, p=0.03) and perceived physical functioning (MVPA β=0.03, p<0.01; LPA β=0.01, p=0.02); MVPA was also associated with physical well-being (β=0.01, p=0.04) and LPA was associated with change in health-related quality of life from baseline to end of intervention (β=0.03, p=0.02 and β=0.02, p<0.01 for Functional Assessment of Cancer Therapy-Hepatobiliary and Functional Assessment of Cancer Therapy-General subscales, respectively).

Due to high heterogeneity of the studies included in the review, it was not possible to determine meta-associations between objectively measured PA levels during the prehabilitation period and health-related or clinical outcomes. The findings of each trial in relation to the impacts of the interventions on health and clinical outcomes are detailed in tables 3 and 4. These results are not discussed further in the text because, due to our inclusion criteria, the studies included in this review represent a very small subgroup of the larger body of evidence that has examined impacts of prehabilitation on these outcomes.

Risk of bias

Risk of bias was deemed to be high for nine articles and low for seven articles; some concerns were noted for the remaining five articles (online supplemental file 2). The most common sources of bias came from issues during randomisation or lack of randomisation all together, reflecting the pilot/feasibility nature of most of the studies. We did not identify high risk of bias in the measurement of the outcome in any articles.

DISCUSSION

This review identified 21 articles based on 15 separate trials that used objective measures of PA within PA interventions prior to surgery. There was a high degree of variability across the studies in terms of surgery type, nature of the prehabilitation intervention, outcome measurements, and completeness in the reporting of PA measurements and outcome variables. The lack of complete and consistent reporting meant that meta-analysis could not be used to estimate pooled effects across studies or to examine the relationships between changes in objectively measured PA and clinical outcomes. Additionally, almost half of the included studies were small feasibility or pilot studies that were not statistically powered to detect associations that were being tested. There is a clear need for more widespread use of accelerometry within large-scale prehabilitation interventions, alongside transparent and consistent reporting of predictor and outcome variables, to improve our understanding of the impact that prehabilitation may have on PA levels and on subsequent clinical outcomes.

Across the studies that examined the impact of prehabilitation on objectively measured PA levels during the intervention period, there was no clear effect. Only one of three RCTs reported a significantly larger increase

Table 3 Physical activity measurements and findings in the presurgery period

Study	Device used and wear protocol	Physical activity variables and their definitions	Physical activity findings	Clinical/health-related outcomes and findings
RCTs				
Bond *et al*[31 44 45]	SenseWear armband worn on the upper right triceps muscle during all waking hours for 7 consecutive days at both baseline and postintervention follow-up (mean 90±65 days preoperation) Minimum wear requirement: ≥6 hours of wear per day on ≥4 days during both the baseline and postintervention follow-up periods	Time spent in MVPA (≥3 METs as determined by SenseWear proprietary software) in total and accumulated in 10 min bouts, and steps per day	MVPA accumulated in 10 min bouts increased in the intervention group by 16.6±20.7 min/day vs no change in control (–0.3±12.7 min/day, p=0.001). Total MVPA increased in the intervention group by 21.0±26.9 min/day vs no change in control (-0.1±16.3 min/day, p=0.001). Daily steps increased in the intervention group by 2027.6±1886.9 steps/day vs no change in control (202.7±1374.3 steps/day, p<0.001)	Intervention group reported significantly greater improvements in health-related quality of life, physical activity enjoyment, physical activity self-efficacy and physical activity motivation from baseline to end of intervention No differences between groups in weight change (kg) over the intervention period
Dronkers *et al*[46]	NL1000 pedometer used to measure daily steps during the intervention period	Mean number of steps per day	There was no significant difference in mean number of daily steps between the intervention (4980) and control (5003) groups (p>0.05), *no SD or CIs provided*	Intervention group had a greater improvement in inspiratory muscle endurance than the control group from baseline to end of intervention. No differences between groups in changes in timed up-and-go test, chair rise time, maximal inspiratory pressure, self-reported physical activity, physical work capacity, fatigue or health-related quality of life from baseline to end of intervention (preoperation), or postoperative complications or length of stay
Huber *et al*[29]	SenseWear armband worn at baseline and postintervention (1-week preoperation) Minimum wear requirement not reported	METs (kcal/hour/kg) and average steps per day determined by SenseWear proprietary software	From baseline to postintervention, there were no significant differences in mean changes in METs (0.3 (95% CI –2.2 to 2.7)) or daily steps (–687 (95% CI –2172 to 798)) between intervention and control group	From baseline to postintervention, there were no significant differences between the intervention and control group in chair stand test, KOOS measurements (function, pain, symptoms, quality of life), knee range of motion, 20 m walk test, timed up and go test, self-reported physical activity or health-related quality of life

Continued

Table 3 Continued

Study	Device used and wear protocol	Physical activity variables and their definitions	Physical activity findings	Clinical/health-related outcomes and findings
Moug *et al*[34 51]	activPAL adhered to the anterior thigh and worn for 3–5 days at baseline and postintervention (1–2 weeks before surgery) Minimum wear requirement not reported	Proprietary activPAL software to determine sedentary time (sitting/lying down), active time and average steps per day	From baseline to postintervention, there were no significant mean differences between intervention and control group in median steps per day (785 (95% CI −1195 to 2765)), per cent of week spent active (0.3 (95% CI −1.7 to 2.2)) or per cent of week spent sedentary (−2.7 (−13.2 to 7.9))	No differences between groups in weight, BMI, waist circumference, sit-to-stand test, 6MWT, quality of life, positive or negative affect scores, depression, Functional Assessment of Cancer Therapy score or muscle mass from baseline to end of intervention
Non-randomised parallel group				
Loughney *et al*[36] and West *et al*[37]	SenseWear Pro armband worn continuously on the upper right arm for three consecutive weekdays (72 hours) worn at baseline (immediately following neoadjuvant chemoradiotherapy) and end of intervention. Participants in the exercise training group removed the monitor during in-hospital exercise training sessions Minimum wear requirement not reported	Step count (steps/day), METs, active energy expenditure (kcal/day), physical activity duration (min/day), lying down (min/day), sleep efficiency (%), sleep duration (min/day) and total energy expenditure (kcal/day) determined by SenseWear proprietary software	From baseline to end of intervention, the intervention group had larger improvements in sleep efficiency (p=0.02), sleep duration (p=0.03) and lying down time (p=0.03) compared with the control group. There were no significant between-group differences in steps per day, METs, active energy expenditure, physical activity duration or total energy expenditure from baseline to end of intervention	The intervention group showed significantly larger improvements in estimated lactate threshold and VO_2 at peak compared with the control group at end of intervention vs baseline. No between-group differences in BMI, forced expiry volume of 1 s (FEV_1), forced vital capacity (FVC), FEV_1/FVC or haemoglobin across the study period
Single-arm trials				
Alejo *et al*[30]	Hip-worn Actigraph GT3x worn for a minimum of 5 days at baseline (before neoadjuvant treatment) and postintervention (immediately before surgery) Minimum wear requirement: ≥10 hours per day on at least 5 days including 2 weekend days	Sedentary time (<100 cpm), time spent in MVPA (≥1952 cpm)	There were no significant changes in sedentary time (mean difference −24 (95% CI −60 to 10) min/week) or MVPA (mean difference 178 (95% CI −21 to 376) min/week) from baseline to postintervention	From baseline to postintervention, there was significant improvement in VO_{2peak}, depression and emotional function No changes in BMI, handgrip strength, 5 repetition sit-to-stand test, anxiety or quality of life
Grimes *et al*[32]	Wrist-worn Axivity AX3 worn 24 hours per day for 7 days prior to the clinic visit (intervention) and 7 days immediately after the visit Minimum wear requirement: >72 hours of continuous wear at both time points	Average acceleration (mg) per day based on auto-calibrated Euclidian norm minus one (ENMO)	There was a significant increase in overall daily ENMO after the standard clinical intervention (median baseline ENMO 14.3 mg (IQR 9.75–22.04), median postintervention ENMO 20.91 mg (IQR 14.83–27.53), p=0.02	No significant difference in self-reported physical activity from preintervention to postintervention

Continued

Table 3 Continued

Study	Device used and wear protocol	Physical activity variables and their definitions	Physical activity findings	Clinical/health-related outcomes and findings
McAdams-DeMarco *et al*[33]	Wrist-worn Actigraph GT9x worn 24 hours a day for the week prior to intervention, and for 1 week following the 1-month and 2-month prehabilitation evaluations Minimum wear requirement: ≥3 days of wear per week	Mean counts per minute	There was no significant change in mean cpm from baseline (1717) to 1 month (1741, 1% change, p=0.90) but there was a significant increase by the second month (2814, 64% change, p=0.004), *no SD or CIs provided*	Compared with age-matched, sex-matched and race-matched controls, length of stay was shorter for patients who had received prehabilitation
Ngo-Huang *et al*[47] and Parker *et al*[52]	Hip-worn Actigraph GT3X+ worn during all waking hours for two consecutive weeks at the approximate midpoint of each phase of therapy and averaged across all programme weeks for each patient Minimum wear requirement: ≥10 hours per day on ≥7 days at each timepoint Non-wear was classified as at least 60 consecutive minutes of zero counts with allowance of up to 2 min with counts 0–100	Time spent in LPA (100-1951 cpm) and MVPA (≥1952 cpm, in total and in bouts lasting ≥10 min) Ngo-Huang 2019 also reported sedentary time (presumably <100 cpm)	Averaged across the intervention period, participants had 923.8±294.5 min/week LPA; 158.7±146.7 min/week total MVPA; 55.1±92.9 min/week MVPA in 10 min bouts and 4462.9±620.2 min/week sedentary time	There were significant improvements in 6MWT distance, five times sit-to-stand test, and 3-metre walk test (metres per second) from baseline to preoperative follow-up visit There were no significant changes in handgrip strength, physical function scores or functional assessment of cancer therapy scores
Williams *et al*[35]	Wrist-worn COOSA Heart Rate Monitor (accelerometer) at baseline, end of telephone intervention (6 weeks) and end of intervention (12 weeks) Minimum wear requirement: not specified	Steps per day	Compared with baseline, daily step counts did not change at 6 weeks (median difference 1750, p=0.07) but did increase at 12 weeks (median 6700 (IQR 3000–14 600)), a significant median increase of 2700/day compared with baseline (p<0.01)	There were significant improvements in incremental shuttle walk test, short physical performance battery tests (including chair stand, balance, gait speed) from baseline to 6 weeks with further improvements in shuttle walk test at 12 weeks. Significant improvements in health-related quality of life were seen from baseline to 12 weeks (but not at 6 weeks) There were no changes in anxiety or depression at any time points

BMI, body mass index; cpm, counts per minute; KOOS, Knee Injury and Osteoarthritis Outcome Score; LPA, light physical activity; METs, metabolic equivalents; MVPA, moderate-to-vigorous physical activity; 6MWT, 6 min walk test; RCT, randomised controlled trial; VO_2, oxygen consumption.

Table 4 PA measurements and findings in the postoperative period (all randomised controlled trials)

Study	Device used and wear protocol	Physical activity variables and their definitions	Physical activity findings	Clinical/health-related outcomes and findings
Au *et al*[38]	Wrist-worn Actiwatch 2 provided shortly after surgery (either in postanaesthetic care unit or on admission to the ward) with inpatient measurement starting at 08:00 on postop day 1 for 24 hours and outpatient measurement starting at 08:00 the first day after discharge for 7 days Minimum wear requirement: ≥10 hours per day (number of days not specified) Non-wear defined as zero activity for 60 consecutive minutes	Time spent in total physical activity (≥100 cpm)	The intervention group had significantly higher total physical activity than the control group on postoperative day 1 (mean difference 117.5 (95% CI 0.04 to 235.0) min) There was no difference between groups in total physical activity during postdischarge week 1 (mean difference −42.6 (95% CI −134.0 to 48.7) min)	No differences in length of stay or days of catheterisation between groups
Baillot *et al*[39]	Hip-worn Actigraph GT3X+ worn during all waking hours for 7 days after the 1-year assessment Minimum wear requirement: ≥9 hours per day on ≥4 consecutive days Non-wear classified as 180 min of consecutive zeroes	Sedentary time (<100 cpm), LPA (100–1951 cpm), moderate PA (1952–5724 cpm) and vigorous (>5724 cpm) Steps per day	Compared with the control group, intervention group had significantly higher steps per day and longer duration of light and moderate PA per day 1 year following surgery (shown graphically; numbers not available). The daily duration of vigorous PA (0.02±0.10 vs 0.01±0.00 hours per day, p=0.42) and sedentary time (10.4±1.2 vs 10.7±1.6 hours per day, p=0.62) did not differ between groups	From baseline to 1-year postsurgery, changes in 6MWT heart cost, half-squat test and BMI were larger in the intervention group compared with the control group No differences between groups in arm curl and sit-to-stand tests, maximal aerobic capacity, weight-related quality of life, physical exercise beliefs and barriers, self-reported PA, neck circumference, fat mass, resting heart rate or blood pressure
Bond *et al*[40]	SenseWear armband worn on the upper right triceps muscle during all waking hours for 7 consecutive days at baseline, postintervention, and at 6 months postoperation Minimum wear requirement: ≥6 hours of wear per day on ≥4 days at all timepoints	Time spent in MVPA (≥3 METs as determined by SenseWear proprietary software) in total and accumulated in 10 min bouts, and steps per day	The intervention group had higher steps per day than the control at postintervention (7950±3286 vs 5601±3368, p=0.031) and at 6 months postoperation (7870±3936 vs 5087±2603, p=0.024). The intervention group also had higher MVPA (accumulated in 10 min bouts) compared with the control at postintervention (26.3±21.3 min vs 11.4±16.0 min, p=0.016) but not at 6 months postoperation (28.7±26.3 min vs 18.5±28.2 min, p=0.15).	N/A

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Table 4 Continued

Study	Device used and wear protocol	Physical activity variables and their definitions	Physical activity findings	Clinical/health-related outcomes and findings
Guinan *et al*[41]	Hip-worn Actigraph GT3X attached with adhesive tape and worn continuously from postoperative day 1 to postoperative day 6 with data from 12:00 on POD1 to 08:00 on POD6 used in analysis	Daily average LPA minutes (100–2019 cpm), total active minutes, and steps	On postoperative day 1, the control group had higher LPA (median 14.5 (IQR=13.0) vs 4.5 (IQR 13.75) min/day, p=0.03), higher total active minutes (median 15.5 (IQR 14.0) vs 5.0 (IQR 16.0), p=0.03) and higher steps per day (115.0 (IQR 299.3) vs 43.5 (IQR 143.5), p=0.04) compared with the intervention group. Time in LPA, total physical activity, and total steps per day did not differ between the two groups on postoperative days 2, 3, 4 or 5	In the preoperative period, the intervention group showed significantly larger improvements in maximal inspiratory pressure and inspiratory muscle endurance; there were no differences in 6MWT distance. In the postoperative period, 6MWT distance was significantly lower in the intervention group compared with the control. There were no differences in maximal inspiratory pressure or oxygen saturation between groups
Huber *et al*[29]	SenseWear armband worn at baseline and 3 months postoperation Minimum wear requirement not reported	METs (kcal/hour/kg) and average steps per day determined by SenseWear proprietary software	From baseline to 3 months postop, there were no significant differences in mean changes in METs (0.3 (95% CI −2.3 to 2.9)) or daily steps (165.7 (95% CI −1288 to 1620)) between intervention and control group	From baseline to 3 months postop, there were no significant differences between the intervention and control group in chair stand test, KOOS measurements (function, pain, symptoms, quality of life), knee range of motion, 20 m walk test, timed up and go test, self-reported PA or health-related quality of life
Lotzke *et al*[42]	Actigraph GT3X+ No further information provided	Steps per day, time spent in MVPA, LPA and sedentary time. No information on what cut-points were used	From baseline to 3 months postop, there were no differences between groups in steps (−0.09 (95% CI −0.50 to 0.32)), MVPA (0.16 (95% CI −0.25 to 0.57)), LPA (0.07 (95% CI −0.33 to 0.48)) or sedentary time (0.00 (−0.41 to 0.40)) (all values are between-group effect sizes) There were also no differences between groups from baseline to 6 months postop: steps 0.25 (95% CI −0.16 to 0.66), MVPA 0.42 (95% CI 0.00 to 0.83), LPA 0.06 (95% CI −0.35 to 0.47), sedentary time 0.21 (−0.21 to 0.62)	There were no significant between-group differences at any time points (end of intervention, 3 weeks, 8 weeks, 3 months, 6 months after surgery vs baseline) in any of the following outcomes: disability, pain intensity, pain catastrophising, fear of movement, self-efficacy for exercise, anxiety, depressed mood, health-related quality of life or patient-reported functioning. There were also no significant between-group differences (at 3 and 6 months postsurgery vs baseline) in 5 min walk distance, 15 m walk (seconds), timed up and go test, 1 min stair climb or one-leg stand test

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Table 4 Continued

Study	Device used and wear protocol	Physical activity variables and their definitions	Physical activity findings	Clinical/health-related outcomes and findings
Sawatzky *et al*[43]	Actical accelerometer worn over right hip during waking hours for 7 day periods at baseline and 3 months postoperatively Minimum wear requirement: >10 hours on ≥4 days	Time spent in total PA (≥100 cpm) and MVPA (≥750 cpm) in ≥10 min bouts and sporadic bouts (≥30 s)	There were no differences between groups in mean MVPA (78 (95% CI −135 to 291) min/week) or total PA (75 (95% CI −221 to 370) min/week) accumulated in 10 min bouts from baseline to 3 months postoperatively. There were also no differences in sporadic MVPA (−37 (95% CI −274 to 198) min/week) or total PA (−91 (95% CI −700 to 518) min/week)	The intervention group had significantly larger improvements in 6MWT distance from baseline to end of intervention and 3 months postoperatively compared with the control group, as well as larger preoperative improvements in 5-metre gait speed (no significant postoperative difference). There were no significant between-group differences in quality of life, depression, anxiety, exercise self-efficacy or in surgical parameters (cardiopulmonary bypass time, ICU length of stay, length of hospital stay)

BMI, body mass index; cpm, counts per minute; ICU, intensive care unit; KOOS, Knee Injury and Osteoarthritis Outcome Score; LPA, light physical activity; METs, metabolic equivalents; MVPA, moderate-to-vigorous physical activity; 6MWT, 6 min walk test; PA, physical activity.

in MVPA and daily steps among the intervention group compared with the control group.[31] It is important to note that this RCT was the only study for which a sample size calculation was reported with change in PA (MVPA) as the primary outcome variable.[31] The remaining RCTs had comparatively small sample sizes and were either powered for a different (non-PA) outcome variable[29] or were feasibility/pilot studies,[34] which may explain their null findings. Data from single-arm studies tended to suggest that prehabilitation was effective for increasing PA levels across the intervention period (three out of four). The trials that reported significant changes in PA were unsupervised home-based interventions,[31 32 35] suggesting such interventions might have a more effective impact on objectively measured PA, although it is worth noting that not all home-based interventions reported an effect.[34] Further randomised studies that are adequately powered to detect changes in objectively measured PA are needed to improve our understanding of the impact of prehabilitation on PA levels.

Among the very few studies in this review that examined associations between objectively measured PA and health-related outcomes, significant associations were reported. For example, Bond *et al*[44] and Ngo-Huang *et al*[47] reported that changes in MVPA during the intervention were associated with improvements in quality of life and physical functioning in the intervention period. These findings suggest that the effects that prehabilitation interventions have on objectively measured PA levels directly correlate with improvements in clinical outcomes. A larger body of evidence-based on accelerometry is required to be able to quantify the volume and/or intensity of PA that patients might be advised to aim for (on a case-by-case basis) in preparation for surgery to optimise clinical outcomes following surgery, as others have similarly suggested.[48] To support the development of this evidence base, prehabilitation studies should use objective measures of PA wherever possible during the intervention. Additionally, studies should endeavour to report descriptive statistics of accelerometry variables and health/clinical outcome variables consistently and in sufficient detail to allow meta-analysis of associations to be possible. As this review has identified, this evidence gap is particularly salient for cardiothoracic surgery patients for whom prehabilitation might be especially important.[49]

We recommend that best practice be followed when objective measures of PA are integrated in future prehabilitation trials to ensure the validity and interpretability of the measurements. When objectively measuring PA (particularly using accelerometry), a number of decisions are required to be made in terms of what device will be used, wear protocol (eg, waking wear or 24-hour wear), minimum wear required to constitute a valid dataset, how to identify and handle periods of non-wear, and the selection of relevant outcome variables and how they will be defined. Best practice depends on what the outcome of interest is (ie, measurement of sedentary time has different considerations than measurement of MVPA); we refer readers to useful reviews for further details.[17 22 50]

This review has several limitations that must be acknowledged. Over half of the included studies were small feasibility or pilot studies for which power calculations were not performed. The null findings throughout this review should thus not necessarily be interpreted as a lack of

effect of prehabilitation. Additionally, the fidelity of the interventions was generally not assessed or reported, thus we cannot rule out the possibility that issues or inconsistencies in intervention implementation within studies may also be at play. Finally, the small number of eligible studies involving a range of surgery types meant it was not possible to do any subgroup analyses to examine any differences in outcomes according to type of prehabilitation programme or type of surgery.

CONCLUSIONS

Few prehabilitation trials have incorporated objective measurements of PA. There is little evidence to suggest that prehabilitation may be effective for increasing patients' PA levels prior to surgery, although the evidence included in this review primarily consisted of small feasibility studies which may not have sufficient statistical power. There was some evidence to suggest that increases in objectively measured PA were associated with improvements in physical functioning and quality of life. Limitations in the evidence base precluded any assessment of pooled associations between objectively measured PA during the intervention period and surgical outcomes. Additional large-scale studies are needed, with clear and consistent reporting of accelerometry variables and outcome variables, to improve our understanding of the impact of changes in PA prior to surgery on health and clinical outcomes.

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