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.

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 stay10–12 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.\textsuperscript{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\textsuperscript{19–22} and have higher measurement validity than subjective methods.\textsuperscript{22} To date, most prehabilitation interventions have used self-report methods to estimate changes in PA levels across the intervention period.\textsuperscript{23–25} However, self-reported measures of PA are not well-suited to capturing changes in PA levels over time\textsuperscript{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 \textit{et al}\textsuperscript{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).\textsuperscript{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

\textsuperscript{2}Wagnild JM, \textit{et al}. \textbf{BMJ} Open 2021;11:e049202. doi:10.1136/bmjopen-2021-049202
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 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 programmes that involved either supervised training sessions in a facility (n=6) or unsupervised home-based programmes (n=5).

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 postintervention (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 postintervention29–35 or the end of the intervention period36–37 (table 3). Among RCTs or non-randomised parallel group trials (n=4), only one study reported a significant difference: Bond et al31 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 level29 34 36 or steps per day29 34 36 37 from baseline to postintervention29 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 al32 and McAdams-DeMarco et al33 reported significant increases in objectively measured total PA from baseline to the end of the intervention and Williams et al35 reported a significant increase in steps per day. Alejo et al34 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 surgery29 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 months40 and steps per day 1 year39 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 total PA,43 steps per day,40 light PA42 or sedentary time42 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 al44 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...
with changes in enjoyment, self-efficacy or motivation for PA (only p values were reported, ranging from 0.20 to 0.90). Dronkers et al. reported a significant correlation (rpb = 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 post-operative pulmonary complications. In a single-arm trial, Ngo-Huang et al. reported that accelerometer-measured MVPA and LPA averaged over the prehabilitation period were each associated with improvement in 6 min walk test.

### 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.   | Spain        | Single-arm            | Surgery for rectal cancer following NACRT             | 12                 | N/A              | 61±7               | N/A             |
| Au et al.      | Canada       | RCT                   | Radical prostatectomy                                 | 19                 | 19               | 61.4±7.8           | 58.4±6.1        |
| Baillot et al. | Canada       | RCT                   | Bariatric surgery                                     | 13                 | 12               | 44.5±8.8           | 41.1±10.3       |
| Bond et al.    | USA          | RCT                   | Bariatric surgery                                     | 40                 | 35               | 44.2±9.2           | 48.1±8.1        |
| Bond et al.    |              |                       |                                                       | 22                 | 14               | 46.4±9.1           | 47.9±6.8        |
| Dronkers et al.| The Netherlands | RCT                  | Elective abdominal oncological surgery                | 22                 | 20               | 71.1±6.3           | 68.8±6.4        |
| Grimes et al.  | 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.  | Ireland      | RCT                   | Oesophagectomy                                        | 28                 | 32               | 63.1±8.8           | 65.1±67.8       |
| Huber et al.   | Switzerland  | RCT                   | Total knee replacement                                 | 22                 | 23               | 68.8±8.0           | 71.9±8.1        |
| Lotzke et al.  | Sweden       | RCT                   | Lumbar fusion surgery                                  | 59                 | 59               | 44.8±8.2           | 46.7±8.5        |
| Loughney et al.| UK           | Non-randomised parallel group | Surgery for rectal cancer                          | 23                 | 10               | 64 (range 45–82)   | 72 (range 62–84) |
| West et al.    |              |                       |                                                       | 22                 | 13               | 64 (range 45–82)   | 72 (range 62–84) |
| McAdams-DeMarco et al. | USA           | Single-arm            | Kidney transplantation                                 | 18                 | N/A              | 52±12.9            | N/A             |
| Moug et al.    | UK           | RCT                   | Surgery for rectal cancer with NACRT                  | 24                 | 24               | 65.2±11.4          | 66.5±9.6        |
| Moug et al.    |              |                       |                                                       |                    |                  | 66.8±9.6 (both arms combined) |
| Ngo-Huang et al. and Parker et al. | USA      | Single-arm            | Pancreatectomy                                        | 50                 | N/A              | 66±8               | N/A             |
| Sawatzky et al.| Canada       | RCT                   | Elective coronary artery bypass graft                 | 8                  | 9                | 64±7               | 63±9            |
| Williams et al.| UK           | Single-arm            | Liver transplantation                                  | 18                 | N/A              | Median 55 (IQR 44–63) | N/A             |

NACRT, neoadjuvant chemoradiotherapy; RCT, randomised controlled trial.
| Study          | Type of programme                      | Frequency and duration of sessions | Programme contents                                                                                                                                                                                                 | Adherence and adverse events (AEs)                                                                 | Control arm                                                                                       |
|---------------|----------------------------------------|-----------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|
| Alejo et al   | 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      | 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 | 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    | 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 |
| Study          | Type of programme                                         | Frequency and duration of sessions                      | Programme contents                                                                                                                                                                                                 | Adherence and adverse events (AEs)                                                                 | Control arm                                                                                       |
|---------------|-----------------------------------------------------------|--------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|
| Dronkers et al | 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  | 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  | 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   | 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 |
| Study             | Type of programme                        | Frequency and duration of sessions | Programme contents                                                                 | Adherence and adverse events (AEs) | Control arm                                                                                     |
|------------------|------------------------------------------|-----------------------------------|-----------------------------------------------------------------------------------|-----------------------------------|-----------------------------------------------------------------------------------------------|
| Lotzke et al⁵²   | 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 al⁶⁶ and West et al⁶⁷    | 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 VO₂ at lactate threshold) to severe (50% of the difference in work rates between VO₂ 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 al³³ | 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                                                                                                                           |
| Table 2 | Study | Type of programme | Frequency and duration of sessions | Programme contents | Adherence and adverse events (AEs) | Control arm |
|---|---|---|---|---|---|---|
| Moug et al<sup>34, 51</sup> | 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<sup>47</sup> and Parker et al<sup>52</sup> | 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 86±3.9% of programme days. No AEs were reported | N/A |
| Sawatzky et al<sup>43</sup> | 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<sub>2</sub>, 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
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 under study. 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 objectively measured PA levels during the prehabilitation period.

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. The most common sources of bias came from issues during randomisation or lack of randomisation, reflecting the pilot/feasibility nature of most of the studies. We did not identify high risk of bias in the remaining five articles.

Table 2

| Study | Type of programme | Frequency and duration of sessions | Programme contents | Adherence and adverse events (AEs) | Control arm |
|-------|------------------|-----------------------------------|--------------------|-----------------------------------|-------------|
| Williams et al | 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; VO2, oxygen consumption.
### 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<sup>31,44,45</sup>                                                                 | 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 202.6±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<sup>46</sup>                                                                 | 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<sup>29</sup>                                                                   | 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 |
### 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\(_2\) peak compared with the control group at end of intervention vs baseline. No between-group differences in BMI, forced expiratory 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\(_{2\text{peak}}\) 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 |
| 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<sup>33</sup> | 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<sup>47</sup> and Parker et al<sup>52</sup> | 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<sup>35</sup> | 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<sub>2</sub>, oxygen consumption.
| Study         | Device used and wear protocol | Physical activity variables and their definitions | Physical activity findings                                                                 | Clinical/health-related outcomes and findings                                       |
|--------------|-------------------------------|-------------------------------------------------|------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| Au et al     | 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 | 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 | N/A |
| Bond et al   | 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 |

Continued
### 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 al41   | 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 al29    | 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 al42   | 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 |

Continued
in MVPA and daily steps among the intervention group compared with the control group. 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. The remaining RCTs had comparatively small sample sizes and were either powered for a different (non-PA) outcome variable or were feasibility/pilot studies, 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.

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. and Ngo-Huang et al. 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 of 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. 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 accelerometer 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.

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.

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 accelerometer 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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