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REVIEW ARTICLE

Use of wearable devices to monitor post-operative activity following cardiac surgery: a systematic scoping review

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Aims

There is an emerging trend of using wearable digital technology to monitor patient activity levels in acute care contexts. However, the overall extent and quality of evidence for their use in acute cardiac surgery care are unclear. The purpose of this systematic scoping review was to evaluate current literature regarding the use of wearable activity trackers/accelerometers to monitor patient activity levels in the first 30 days following cardiac surgery.

Method and results

A systematic scoping review was conducted. A search of CINAHL and MEDLINE Complete databases identified all peer reviewed research evidence published in English between 2010 and 2023. Studies evaluating the use of wearable technology in adults who had undergone coronary artery bypass graft surgery and valve replacement were included. Study data were summarized thematically. A total of 853 citations were identified. Once duplicates were removed, 816 studies were screened by title and abstract, 54 full-text studies were assessed for eligibility, and 11 studies were included. Accelerometers were able to capture changing exercise and physical activity levels over an acute care admission. Device use was acceptable to clinicians and patients. Low activity levels in the early post-operative period were associated with longer length of stay and higher 30-day readmissions.

Conclusion

Wearable devices are acceptable and feasible to use in acute care. The use of wearable activity trackers by acute cardiac patients may increase patient participation in exercise and identify more sedentary patients who are a greater risk of increased length of stay and hospital readmission.

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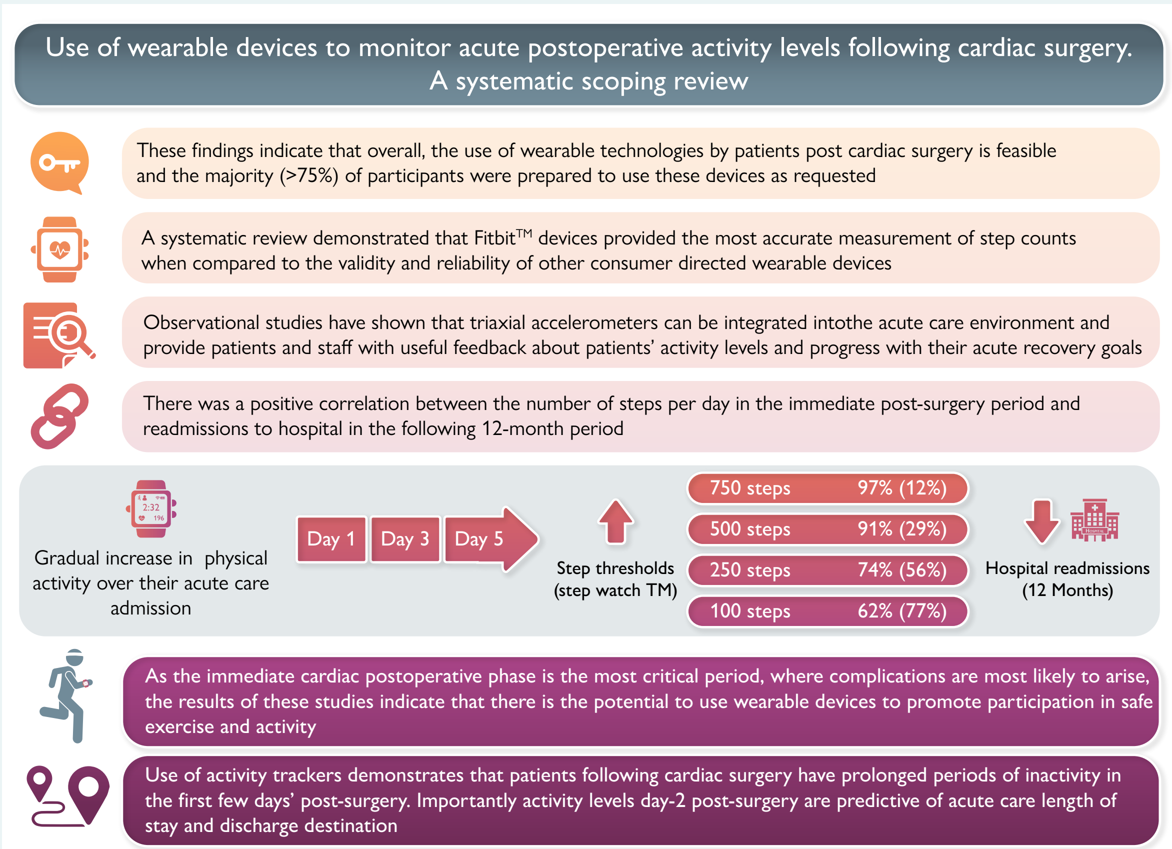
Graphical Abstract



Keywords Cardiac–thoracic nursing • Cardiac surgery • Exercise participation • Exercise rehabilitation • Patent participation • Post-operative recovery • Wearable activity trackers

Novelty

- This is the first systematic scoping review to evaluate the evidence for the use of wearable activity trackers in acute care following cardiac surgery.
- These review findings indicate that wearable activity trackers are feasible and acceptable to use, and the measured activity levels can predict acute care readmission.

Introduction

Cardiovascular diseases are one of the major causes of mortality and morbidity globally.[1–3] For patients with advanced coronary artery or cardiac valve disease, surgical interventions such as coronary artery bypass graft (CABG) surgery[4] and valve replacement (VR) surgery[5] are a key component of effective treatment. Immediately following cardiac surgery, early mobilization is crucial[1–4] and it is fundamental to achieving optimal outcomes that patients participate in a structured exercise programme during their acute care admission.[6,7] There has been considerable research exploring how early mobilization post-cardiac surgery impacts on patient health outcomes[8]; however, the reproducibility of these studies has been limited by a lack of objective measurements of patient activity levels. Following cardiac surgery, immobility contributes to decreased cardiac output states and increases the occurrence of respiratory infections, venous thromboembolism, deconditioning, and pressure sores.[9] Current evidence suggests that in comparison with bed rest, early mobilization post-cardiac surgery is more effective than other interventions in improving functional recovery.[1,6–10] Despite this evidence for improved outcomes, barriers to patient participation in exercise in acute care settings persist. Szylinska *et al.*,[11] for example, found that 78% of patients reported a lack of time or that they were too unwell to participate in inpatient rehabilitation.

Wearable activity trackers such as triaxial accelerometers have been shown to be feasible, objective measures of upper and lower limb movement and mobilization in ambulatory rehabilitation settings.[12–14] However, there is limited research evaluating their use specifically post-cardiac surgery in the context of acute care.[15] When used in acute care settings, accelerometers have been shown to be a feasible method to measure physical activity levels following laparoscopic abdominal surgery[16] and may also detect periods of prolonged inactivity and decreased mobilization.[15] The use of accelerometers has also been shown to be feasible in paediatric surgical population providing parents, children, and clinicians with a more objective measure of paediatric patients' recovery trajectory.[17] These findings highlight that objective measures of patient activity levels following surgery may provide an indication of cardiac patients' functional recovery and motivate patients to participate in exercise following their cardiac procedure.

The purpose of this systematic scoping review was to evaluate and synthesize the current peer-reviewed literature regarding the use of wearable activity trackers to monitor patient activity levels in acute care and for the first 30 days immediately following cardiac surgery.

Methods

A systematic scoping review via electronic database searches was used to address the study purpose.[18] A systematic scoping review methodology was used as this approach provided a systematic and rigorous approach to summarizing the extent of the current literature in this emerging field. The methodology review was guided using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses checklist for systematic scoping reviews and the recommended methodology for scoping reviews outlined by Peters *et al.*[19]

Search strategy

Citations were searched within CINAHL Complete and MEDLINE Complete databases between January 2010 and November 2023 dates, with search terms combined according to a PCC (Participant, Concept, Context) framework as per Joanna Briggs Institute.[20] Search terms were related to (i) cardiac surgery procedures; (ii) wearable technology, wearable activity trackers, including popular trademark names; and (iii) relevant outcomes of interest. Individual keywords, their synonyms, and relevant Medical Subject Headings were combined as per the National Library of Medicine.[21] The literature search was limited to English language publications. Paediatric publications were excluded.

Definitions

Wearable activity trackers were operationally defined as devices used for continuous measurement of upper and lower limb activity. Triaxial accelerometers are one type of widely used activity tracker that measures gravitational and inertial acceleration. These devices provide inclination sensing in response to gravity and this inclination data can provide information on body posture orientations, upper and lower limb movement, and total daily activity levels.[5] These devices are developed to learn movement patterns and establish algorithms that can be used to determine body position and movement (e.g. whether individuals are lying, sitting, standing, walking, or running). The physical activity data obtained from these devices have been reported as highly accurate.[5]

Study screening

Studies were screened independently by two reviews against the study inclusion and exclusion criteria. Inclusion criteria were as follows: studies involving adults aged 18 years and above who had undergone invasive cardiac surgery procedures via sternotomy. Invasive cardiac procedures included CABG surgery and/or valve replacement or repair (VR) only. Exclusion criteria were as follows: studies evaluating the use of activity monitors or accelerometers in ambulatory, primary, or secondary care more than 30 days after cardiac surgery procedure. Studies published in languages other than English were excluded.

Quality appraisal and level of evidence

The quality of the included studies was evaluated by two independent reviewers (J.E. and D.K.). The study design for each included study was identified and the relevant Joanna Briggs Institute checklist[22] was selected. Each reviewer evaluated each quality criterion and coded using the following criteria: yes criteria addressed, no not addressed, unclear, or missing. Differences between reviewers were resolved by discussion with all members of the research team until a consensus was reached. Studies were not excluded based on the quality appraisal. The level of research evidence each study provided was evaluated using the National Health and Medical Research Council of Australia criteria.[23] As the included studies included both interventional and diagnostic accuracy studies, studies were reviewed according to the relevant criteria dependent on the purpose of the study.

Data extraction and synthesis

The management of study data and review citations was monitored using Covidence.[24] The imported papers were initially screened by two researchers (J.E. and A.H.). The studies were then divided alphabetically and assessed for eligibility by two of the four researchers (J.E., A.H., D.K., and J.M.) against the study inclusion and exclusion criteria. Weekly discussions via Zoom were conducted until consensus was reached on study inclusion. Data were extracted from included papers that measured the following study outcomes: device accuracy, useability, inpatient activity levels, activity levels (step counts, distance, duration, and intensity) to 30 days after discharge, use of activity trackers to measure the association between functional recovery (step counts) and discharge destination, acute care length of stay, and acute health care readmission (at 12 months) after discharge. The study data were then extracted into a data extraction table that summarized the study characteristics—reference, study setting including country, surgical intervention, type of wearable technology, study design, study sample, data collection period including weeks post-operatively, and outcome measures. Study outcomes were then summarized in separate tables. Outcomes considered included the acceptability, useability, accuracy of wearable activity trackers, and the impact on patient participation in exercise and clinical outcomes in the first month following surgery. Studies that contained data longer than 30 days post-operatively only had data up to 30 days following surgery included.

Results

A total of 852 studies were identified, and once duplicates were removed, 816 studies were screened by title and abstract for inclusion and 54 full-text studies were assessed for eligibility. After exclusion based on criteria of eligibility, 11 studies were included in the review (*Figure 1*). Study quality appraisals are summarized in *Figure 2*. The characteristics of each study were identified (*Table 1*) and outcome measures and data were extracted for further analysis.

Study characteristics

Table 1 presents the characteristics of the included studies. These studies were published between January 2000 and November 2023 and varied from smaller medical centres to major tertiary hospitals. The types of wearable technology compared across studies included activity monitors using accelerometer technology and electronic activity tracker bracelets. Eight studies measured device useability[25,27–33]; $n = 1$ accuracy of wearable devices[24]; $n = 5$ exercise participation in acute care[5,26,31,32,34]; $n = 5$ using activity trackers to measure exercise participation in the first 30 days following surgery[25,26,29,32,34]; and $n = 3$ association between exercise/activity levels with inpatient length of stay and acute care readmission.[25,31,32] These outcomes are shown in *Tables 2–6*.

Acceptability and useability of wearable activity trackers

All studies were appraised to determine whether the acceptability and useability of wearable monitoring devices were evaluated. For this

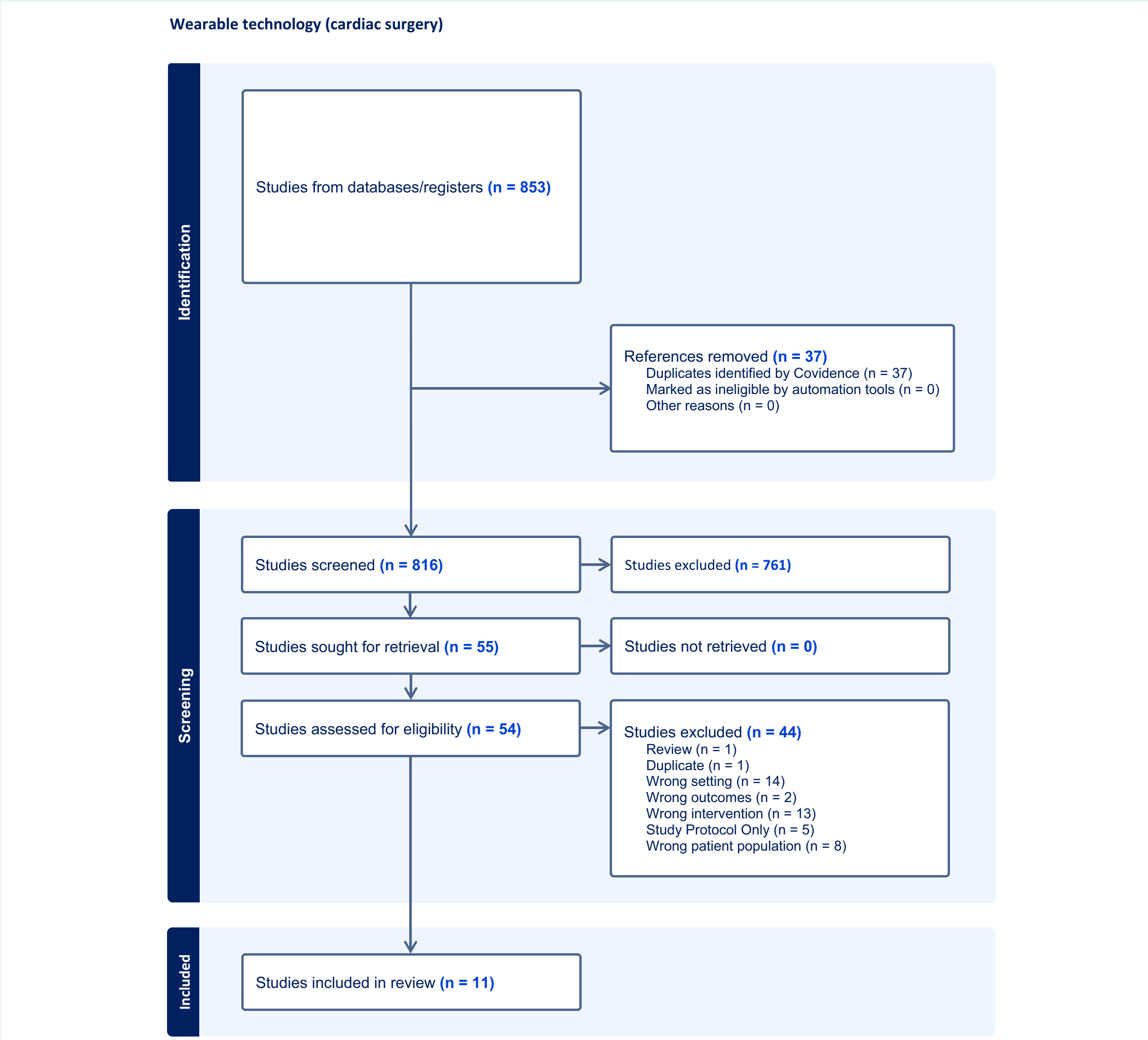


Figure 1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram of screened and included studies.

study, usability was defined as the number of participants who wore the device correctly for the duration of the study. Acceptability was measured by patient reports of satisfaction with using the device. Of the 11 studies examined, eight studies reported usability and no studies measured patient satisfaction (acceptability) with the use of the device. These data are summarized in *Table 2*. The number of participants completing the study data collection as planned ranged between 73%[32] and 89%[25] to 94%.[30]

Accuracy of wearable activity trackers

One study evaluated wearable device accuracy compared with video footage of patients walking under controlled conditions (*Table 3*). Daligadu *et al.*[28] compared a commercially available triaxial accelerometer [the Fitbit Flex13™ (Fitbit Inc., Boston, MA)] that can estimate the number of steps taken and walking distance to a manual count obtained from simultaneously recorded videos of inpatient cardiac patients. This study found that the steps counted and distance walked were significantly different between the Fitbit Flex13™ and the reference standard ($P < 0.05$), suggesting that the reliability and accuracy of the Fitbit Flex13™ were modest. This finding indicates that this device may be useful to provide trend data on patient activity levels but does not provide an accurate measure of activity.

Measurement of exercise participation in acute care

Five studies[5,26,31,32,34] were identified that provided detailed measures of cardiac surgical patients' exercise type and activity levels during their acute care admission (*Table 4*). Halfwerk *et al.*[5] used a triaxial accelerometer (AX3, Axivity™) to capture activity levels and artificial neural network analysis to estimate daily activity time between 7 a.m. and 11 p.m. for the first 6 days following cardiac surgery. In this study, patients exercise duration increased and patients were more likely to be sitting out of bed and begin

Studies of diagnostic accuracy	Consecutive or random sample?	Case control design avoided?	Avoid inappropriate exclusions?	Test result interpreted without knowledge of the reference standard?	If a threshold was used, was it pre-specified?	Reference standard likely to correctly classify the target condition?	Reference standard interpreted without knowledge of the results of the index test?	Appropriate interval between index test and reference standard?	All patients receive the same reference standard?	All patients included in the analysis?	
Daligadu et al. (2018)	?	+	+	?	+	+	?	+	+	+	

Prospective cohort studies	Similar groups recruited from the same population?	Similar measure of exposure?	Exposure measured in a valid and reliable way	Confounding factors identified?	Strategies to deal with confounding factors stated?	Groups free of the outcome at the start of the study	Outcomes measured in a valid and reliable way?	Follow up time reported sufficient for outcomes to occur?	Follow-up complete?	Strategies to address incomplete follow-up used	Appropriate statistical analysis used?
Brown et al. (2022)	+	+	+	+	+	+	+	+	+	NA	+
Cotton et al (2022)	+	+	+	+	NA	+	+	+	+	NA	+
Cook et al. (2013)	+	+	+	+	+	+	+	+	+	NA	+
Gray et al. (2022)	+	+	+	-	-	+	+	+	+	NA	+
Halfwerk et al. (2021)	+	+	+	NA	NA	+	+	+	+	NA	+
Hauguel-Moreau et al. (2020)	+	+	+	+	+	+	+	+	+	NA	+
Mungovan et al. (2017)	+	+	+	+	NA	+	+	+	+	NA	+
Takahashi et al. (2015	+	+	+	?	+	+	+	+	?	?	+
Thijs et al (2019)	+	+	+	+	+	+	+	+	-	-	+
Van Bakel (2023)	+	+	+	+	+	+	+	+	+	+	+

Figure 2 Quality appraisal of included studies using Joanna Briggs checklists.

mobilization independently as the days progressed.[5] The proportion of time spent lying in bed each day significantly decreased, while the proportion of sitting, standing, walking, cycling, and using stairs significantly increased each day. It was reported that men had consistently walked a longer distance ($P < 0.001$) and had higher activity time than women ($P < 0.001$). No differences between men and women were observed in this study, with both groups spending 41 (20–62) min less time in bed for each consecutive hospital day ($P < 0.001$).[5]

Another study by Mungovan *et al.*[31] used triaxial accelerometers (Sensewear Pro3™ armband manufactured by BodyMedia, Inc., Pittsburgh, PA, USA) to measure 83 patients' activity levels [measured as daily step counts and metabolic equivalents (METs)] on Days 1–6 post-operatively. This study showed that patients increased both their physiotherapist-supervised ($P < 0.001$) and independent ($P < 0.001$) activity time during their acute care admission. For example, on post-operative Day 6, men walked a mean of 393 (SD 108) m and women walked 300 (SD 121). Men were recorded as walking a significantly greater distance than women ($P = 0.005$). The participants increased the number of minutes spent doing physiotherapy-supervised exercise and independent physical activity and combined steps from Days 1 to 5 post-operatively. The duration of supervised, independent, and overall light exercise (<3 METs) significantly increased over time and was higher in men relative to women. The authors reported that there was a significant correlation ($P < 0.001$) between patients' functional recovery at discharge measured by 6-min walking distance and patients' total step count (combined physiotherapist supervised and independent walking distance) during their acute care admission. Pre-operative lung function (measured as vital capacity) and duration of surgery were the strongest independent predictors of total daily activity levels.

Takahashi *et al.*[32] used a triaxial accelerometer (Active Style Pro HJA-350IT™) to measure patients' daily step count immediately following cardiac surgery. The average daily step count in the last 3 days prior to discharge was mean 2460 (SD 1549) steps. No details were provided on progressive improvement in exercise tolerance and activity levels during patients' acute care admission. At discharge from acute care, there was no significant difference in exercise tolerance by surgery type or complexity ($P = 0.83$). In contrast, Cotton *et al.*[26] measured daily step counts from post-operative Day 1 and found there was a significant difference in median step counts on Day 1 between cardiac surgery and thoracic surgery patients [median (25–75%) cardiac surgery 53 (0–120) vs. thoracic surgery 393 (184–703), $P = 0.02$]. Increase in the number of steps walked per day was not, however, statistically significant over the first week of recovery post-operatively. van Bakel *et al.*[34] evaluated the activity levels of 165 patients admitted following either ST-segment elevation myocardial infarction (MI) (50%) or non–ST-segment elevation MI (50%), of these $n = 15$ (9%) underwent CABGs. For the whole cohort, patients spent 1.1 [95% confidence interval (CI), 0.8–1.6] h/day participating in light physical activity and 0.2 (95% CI, 0.1–0.3) h/day in moderate to vigorous physical activity.

Exercise participation following acute care discharge

Five studies[25,26,29,32,34] evaluated the effect on exercise participation of supplying patients who had undergone cardiac surgery with an accelerometer at acute care discharge.

Table 1 Characteristics of included studies ($n = 11$)

First author	Study setting, country	Surgical intervention	Type of wearable technology	Study design/ level of evidence	Study sample	Data collection period	Outcome measures
Brown *et al.*[25]	John Hopkins, USA	CABG with sternotomy and/or valve surgery, aortic surgery, myectomy.	Three devices: 1. StepWatch™ Ambulation Monitor 2. Fitbit Charge HR™ 3. ActiGraph GT9X™ and, 4. Criterion Measure: Johns Hopkins Highest Level of Mobility scale.	Prospective cohort study **Evidence Level II (Prognosis/ Prediction)**	$n = 193$ median age 67 (interquartile range 58–72) years	Days 1–10 post-surgery	'Early activity' defined as activity on Day 2 post-surgery. Comparison of activity levels between three devices. Activity Day 2 and hospital length of stay, 30-day readmission and discharge destination.
Cotton *et al.*[26]	School of Medicine Colorado, USA	Video-assisted thoracoscopic surgery (VATS) Or cardiac surgery	Garmin activity monitoring wristband Vivofit3™	Prospective cohort study **Evidence Level II (Prognosis/ Prediction)**	$n = 21$ 7 (33%) VATS 14 (67%) cardiac.	Days 1–28 post-surgery	Median steps per day over 4 weeks. Comparison of recovery trajectory between thoracic and cardiac surgery patients
Cook *et al.*[27]	Mayo Clinic Minnesota, USA	Acute cardiac surgical patients	Fitbit™ wireless accelerometer	Prospective cohort study **Evidence Level II (Prognosis/ Prediction**	$n = 149$ Median age 67 ± 9 years Procedures: Valve 64 (43%) CABG 48 (32%) Combined 21 (14%) Myectomy 8 (5%) Aortic aneurysm 6 (4%) Other (2%)	Day 1 post-surgery to discharge	Activity Days 1–5 and hospital length of stay, and discharge destination.
Daligadu *et al.*[28]	Major urban cardiac surgery centre, Canada	CABG or AVR or MVR	Fitbit Flex™ Versus Reference standard: Video recorded step count	Diagnostic accuracy study **Evidence Level III-I (Diagnostic accuracy)**	20 adult post-operative CABG and/or valve surgical patients without complication	1–2 days before discharge (approx. up 1 week post-operative)	6MWT step count and distance walked using Fitbit Flex to determine validity during the in-hospital phase of recovery
Gray *et al.*[29]	Tertiary hospital in Aotearoa, New Zealand	CABG	Accelerometer ActiGraph 3TGX™	Prospective observational mixed methods study **Evidence Level (N/A)**	12 adult patients post CABG	Weeks 1, 3, 6, and 12	Physical, psychological, and environmental factors that influenced patients' physical activity post CABG surgery
Halfwerk *et al.*[5]		CABG or valve repair or		Prospective			Daily duration in minutes of activity

Continued

Table 1 *Continued*

First author	Study setting, country	Surgical intervention	Type of wearable technology	Study design/ level of evidence	Study sample	Data collection period	Outcome measures
	Medical centre, the Netherlands	replacement with or without CABG	Triaxial accelerometer AX3, Axivity™	single-centre cohort study **Evidence Level II (Prognosis/ Prediction)**	29 cardiac surgical patients	Up to 7 days (1 week post-operative)	performed in a 16-h period. Length of both ICU stay and surgical ward stay in nights
Hauguel-Moreau *et al.*[30]	Teaching cardiothoracic hospital, France	CABG or valve replacement or repair	Electronic activity tracker bracelet Withings Go1™ electronic bracelet	Prospective cohort study **Evidence Level II (Prognosis/ Prediction)**	100 cardiac surgical patients	From discharge to 60 days post-discharge (8 weeks post-operative)	Daily step count Safety and satisfaction of using the electronic activity tracker bracelet
Mungovan *et al.*[31]	Major metro private hospital, Australia	Cardiac surgery via a median sternotomy	Accelerometer and skin sensors Sensewear Pro3™	Prospective observational study **Evidence Level II (Prognosis/ Prediction)**	83 patients undergoing cardiac surgery	Up to 5 days post-operatively 1. Compliance 2. Physical Activity	Step count and physical activity intensity Physiotherapist-supervised exercise and independent physical activity
Takahashi *et al.*[32]	Cardiovascular centre, Japan	CABG and/or valve replacement or valvuloplasty	Triaxle Accelerometer Active Style Pro HJA-350IT™	Prospective cohort study **Evidence Level II (Prognosis/ Prediction)**	133 patients who underwent cardiac surgery	Up to 2 weeks post-operatively, follow-up 1 year later	Step count
Thijs *et al.*[33]	University hospital, Belgium	Off-pump coronary artery bypass (OPCAB) or robotically assisted minimally invasive (RA-MIDCAB)	Fitbit Charge HR™	Prospective cohort study **Evidence Level III-2 (Intervention)**	22 cardiac surgical patients (10 = RA-MIDCAB and 12 = OPCAB)	Up to 4 weeks post-discharge	Physical activity score measured by the Fitbit activity tracker data during the two periods and post-operative complications.
van Bakel *et al.*[34]	Radboud University Medical Center, Nijmegen, the Netherlands	CABG	ActivPAL™ triaxial accelerometer	Prospective cohort study **Evidence Level II (Prognosis/ Prediction)**	The total sample of 165 patients included 15 CABG patients	During hospitalization and the first week of discharge	Sedentary time, sleep duration, light-intensity physical activity time, moderate-vigorous intensity physical activity time

CABG, coronary artery bypass grafts; OPCAB, off-pump coronary artery bypass; RA-MIDCAB, robotically assisted minimally invasive; VATS, video-assisted thoracoscopic surgery.

Table 2 Acceptability and usability of wearable devices ($n = 8$)

Reference First author	Type of Wearable Technology	Where Device Worn	Procedure	Usability	Acceptability
Brown *et al.*[25]	Three devices: 1. StepWatch™ 2. Fitbit Charge HR™, 3. ActiGraph GT9X™	Device 1: worn on ankle. Devices 2 and 3: both worn on same wrist.	Monitoring was commenced by 0800 h the morning following surgery. Patients encouraged to always wear the devices (except when showering).	89% ($n = 193$) of patients who wore the device completed the study. A total of 98% ($n = 189$) wore at least one of the activity devices.	Not reported
Cook *et al.*[27]	Fitbit™ wireless accelerometer	Worn on ankle.	The devices were placed on patients' ankles after transition from the intensive care unit (ICU).	A total of 149 patients were included in the study. The trial uptake was not reported.	Not reported
Cotton *et al.*[26]	Vivofit3™	Worn on non-dominant wrist	Post-operatively, daily steps were recorded for 28 consecutive days, beginning on post-operative Day 1 regardless of disposition (intensive care, floor, or home). Patients wore the activity monitor continuously.	30 patients were enrolled, 7 were lost to follow-up and 2 had incomplete pre-operative walking data. There were 21 (70%) patients included in analysis due to incomplete data collection. 374 screened 30 enrolled	Not reported
Daligadu *et al.*[28]	Fitbit Flex™ Triaxial accelerometer	Worn on non-dominant wrist.	Participants recruited 1–2 days before hospital discharge. During 6-minute walk test data recorded. Activity data communicated wirelessly to a website that tracked activity levels.	Trial uptake 20/32 (62.5%) patients screened.	Not reported
Gray *et al.*[29]	ActiGraph 3TGX	Right hip via clip on waistband	Worn for at least eight hours during the day for five consecutive days during Weeks 1, 3, 6, and 12 post-discharge.	18 eligible 11 consented 2 withdrawn from study post op complications (9/18 50%).	Not reported
Hauguel-Moreau *et al.*[30]	Withings Go™	Worn on the wrist.	Worn continuous pre surgery up to Day 60 after discharge.	100 patients included and 86 agreed to participate. Compliance was 94%.	Not reported
Takahashi *et al.*[32]	Triaxial Accelerometer Active Style Pro HJA-350IT™, Omron Healthcare	Worn on a wrist.	160 patients consented to participate. Patients were instructed to wear the monitor throughout the day for a period of at least 8 h.	27 (17%) withdrew prior to study completion	Not reported
Thijs *et al.*[33]	Triaxial Accelerometer Fitbit Charge HR™	Worn on a wrist.	Patients with fitted with the FitBit Charger and asked to wear the device for 14 days linked to an interface—where patients can review their activity levels/progress.	1 patient withdrew	Not reported

Gray *et al.*[29] conducted a mixed methods study evaluating 12 patients who had undergone cardiac surgery experiences and activity levels (measured using the accelerometer ActiGraph 3TGX™) following discharge from acute care. In this study, the acute care length of stay was mean 7.2 days (range 5–6 days). No details were provided regarding activity levels during hospital admission. In the first week post-acute care discharge, the accelerometer data demonstrated that patients performed an average 1117 ± 824 (range 362–2889) steps/day (*Table 5*) and that patients spent most of their time participating in light activity. By 3 weeks after discharge, patients were spending 89.4 ± 50.4 min/day doing light activity and 14.8 ± 18.2 performing vigorous activity.

Thijs *et al.*[33] compared progressive improvement in activity levels (measured using a Fitbit Charge HR™ activity tracker), between two groups of patients who underwent coronary artery bypass surgery. The first group ($n = 12$) had conventional off-pump CABGs and the

Table 3 Accuracy of accelerometers to measure exercise and activity levels in acute care

Study outcome/ first author	Study findings			Interpretation
6MWT	Distance walked, metres, *M* (SD)	Step count, *M* (SD)	Gait speed, m/s, *M* (SD)	
Daligadu *et al.*[28]	Fitbit Flex™ = 295.3 (95.7) Criterion measure = 246.1 (70.0) M_{diff} (95% CI): 49.1 (5.9–92.3), $P = 0.03$	Fitbit Flex™ = 415.3 (135.9) Criterion measure = 504.3 (77.6) M_{diff} (95% CI): 89.1 (138.0–40.1), $P = 0.01$	Fitbit Flex™: N/A Criterion measure = 0.7 (0.2)	Measurements of 6MWT distance walked and step count were significantly higher in the Fitbit Flex vs. the criterion measure.

6MWT, 6-minute walking test; CI, confidence interval.

second ($n = 10$) had robotically assisted minimally invasive bypass surgery. Acute care length of stay was mean 7 days (range 5–15) for Group 1 and 6 days (range 4–12) for Group 2. In the first week following hospital discharge, Group 1 had a median daily step count of 1110 steps (range 739–10 195) and Group 2 a median step count of 3715 steps (range 1637–6720). This difference was not statistically significant ($P = 0.06$).

Hauguel-Moreau *et al.*[30] evaluated the use of the Withings Go1™ electronic bracelet as an activity tracker. One hundred cardiac patients were given the activity tracker on the day of discharge from acute care and used it for 60 days after discharge. Mean length of stay in the hospital was 11 days with a range of 10–14 days. At discharge, the mean number of daily steps was 1454 ± 145 steps, reaching 5801 ± 580 steps at Day 60. Patients achieved 85% of the maximum activity levels by Day 30 30 (27–33) days after discharge.

Cotton *et al.*[26] found that there was a significant improvement in ambulatory recovery each week for the first 28 days following both thoracic and cardiac surgery, but the trajectory of functional recovery varied between the two groups. The thoracic surgery patients' ambulatory recovery peaked at the end of Week 1, while the cardiac surgery patients' peak recovery was achieved in Week 4 after surgery. In line with these findings, van Bakel *et al.*[34] reported that following discharge home, most patients admitted with ischaemic heart disease significantly increased their activity levels. The time spent participating in light physical activity increased to 2.9 (95% CI, 2.0–3.8) h/day and moderate to vigorous activity increased to 0.6 (95% CI, 0.3–0.9) h/day during the first week at home. Sedentary time did not, however, decrease significantly in the subgroup of patients who underwent CABGs [−0.3 (95% CI, −1.2 to 0.5) h/day, $P = 0.43$] following discharge and activity time did not significantly increase.

Impact of exercise participation on acute care length of stay and readmissions

Four studies evaluated the association between exercise and activity levels, and acute health care utilization. These outcomes are presented in *Table 6*. Cook *et al.*[27] evaluated patient activity levels using a FitBit™ and reported that there were significant differences in the mobility levels on Day 2 following surgery between patients who were discharged home (675 steps on Day 2) compared with those who were discharged to supported care or residential aged care (108 steps on Day 2, $P < 0.001$).

Brown *et al.*[25] measured patient activity levels on Day 2 following cardiac surgery using four different activity measures [three accelerometry devices (StepWatch™, Fitbit™, and ActiGraph™) and one clinical observation scale (Johns Hopkins-Highest Level of Mobility scale)] to evaluate whether activity levels on Day 2 predicted in-patient length of stay. Brown *et al.* showed that the StepWatch™ (*Table 5*) provided the highest discrimination (area under the curve receiver operating characteristics curve 0.71–0.76), to identify patients with a length of stay of greater than 7 days and who required readmission within 30 days. A step count on Day 2 following surgery of 250–500 steps/day identified 74–96% of patients with the above outcomes.

Mungovan *et al.*[31] found that mean length of hospital stay was negatively correlated with overall physiotherapists supervised and independent step counts ($R = -0.62$) and combined physiotherapist-supervised ($R = -0.65$) and independent ($R = -0.43$) physical activity time ≥ 3 METs.

Takahashi *et al.*[32] used a triaxial accelerometer (Active Style Pro HJA-350IT™) to measure daily step count immediately following cardiac surgery. Re-hospitalization for cardiac causes occurred in 16/133 (12.0%) over a 12-month follow-up period. This group of patients had a lower average step count over the last 3 days before discharge than those who were not re-hospitalized (1297 ± 1232 vs. $2620 \pm 1{,}524$, $P < 0.01$). Cox proportional hazard analysis revealed that the strongest predictor of cardiac re-hospitalization was a low step count prior to discharge (≤1308 steps, hazard ratio: 7.58; 95% CI, 2.04–28.22). The cut-off value that predicted the occurrence of cardiac re-hospitalization on the receiver operating curve was 1308 steps/day (area under the curve: 0.783; $P < 0.001$; sensitivity: 0.814; specificity: 0.733).

Discussion

The outcomes of this systematic scoping review demonstrate that it is feasible and acceptable to patients following cardiac surgery to use wearable activity trackers to monitor their activity levels following surgery. Accelerometers can capture changing trends in exercise and physical activity levels over an acute care admission. Low activity levels in the early post-operative period are associated with longer length of stay[28,31] and higher 30-day[31] and 12-month readmissions.[30]

There was some variation in patient adherence with using the triaxial accelerometer devices. One study with a smaller sample size found that most participants completed the study.[32] In contrast, two studies with larger sample sizes reported higher rates of participant withdrawal due to technical issues and non-compliance.[30,32] Hauguel-Moreau *et al.*[30] reported 15% of participants withdrew due to technical issues and 6% due to low compliance, and Takahashi *et al.*[32] reported that 17% of participants in their study withdrew during follow-up. These findings indicate that overall, the use of wearable technologies by cardiac patients is feasible and the majority (>75%) of participants were prepared

Table 4 Exercise and activity levels in the early post-operative period

Author/activity	**Patient outcomes**		
Halfwerk *et al.*[5]	**POD 1**	**Increase per day**	**Increase, men vs. women**
Duration of physical activity, mean estimate minutes (95% CI)			
Walking	−0.39 (−2.6 to 1.8)	2.0 (1.5–2.6), $P < 0.001$	1.1 (−2.4 to 4.7), $P = 0.53$
Cycling	1.4 (−3.9 to 6.8)	1.4 (−0.13 to 2.9), $P = 0.070$	4.2 (−2.4 to 11), $P = 0.21$
Stairs	0.42 (−1.0 to 1.9)	0.68 (0.3–1.1), $P = 0.001$	0.64 (−1.3 to 2.5), $P = 0.5$
Lying in bed	413 (340–487)	−41 (−62 to −20), $P < 0.001$	11 (−78 to 100), $P = 0.81$
Sitting	294 (208–379)	19 (−5.3 to 44), $P = 0.12$	−72 (−175 to 31), $P = 0.17$;
Standing	14 (−0.1 to 28)	5.7 (1.8–9.5), $P = 0.004$	−2.0 (−21 to 17), $P = 0.83$
Percentage of the day (%)			
Walking	− 0.12 (−0.19 to 0.67)	0.55 (0.36–0.74), $P < 0.001$	0.81 (−0.48 to 2.1), $P = 0.21$
Cycling	− 0.08 (−0.74 to 0.58)	0.24 (0.06–0.43), $P = 0.01$	0.51 (−0.34 to 1.4), $P = 0.23$
Stairs	−0.15 (−0.40 to 0.09)	0.17 (0.11–0.24), $P < 0.001$	0.13 (−0.2 to 0.46), $P = 0.43$
Lying in bed	60 (52–68)	−6.5 (−8.7 to −4.2), $P < 0.001$	0.05 (−11 to 11), $P = 0.99$
Sitting	40 (32–48)	3.8 (1.7–6.0), $P < 0.001$	−2.1 (−13 to 9.0), $P = 0.7$
Standing	− 0.57 (−2.7 to 1.5)	2.1 (1.6–2.7), $P < 0.001$	1.4 (−2.0 to 4.7), $P = 0.41$.
Mungovan *et al.*[31]	**POD 1**	**POD 5**	**Overall**
Total PT-supervised exercise, min Mean (SD)	34 (10)	41 (17)	189 (35)
<3 METs, min, mean (SD)			
PT-supervised exercise	0 (0)	10 (8)	25 (21)***
Independent physical activity	0 (1)	12 (20)	23(30)**
Combined activity	0 (1)	22 (24)	48 (46)*
Daily steps, mean (SD)			
PT-supervised exercise	4 (9)	1333 (786)	2834 (2204)***
Independent physical activity	22 (29)	1414 (1829)	2852 (3305)***
Combined steps	27 (3)	2547 (2336)	5686 (5121)***
Takahashi *et al.*[32]	**POD 1**		
Daily steps, last 3 days before discharge, mean (SD)	NR	NR	2460 (1549)
CABG	NR	NR	2336 (1815)
Valve replacement/valvuloplasty	NR	NR	2521 (1336)
Complex surgery (e.g. CABG plus valve replacement)	NR	NR	2496 (1857)
Cotton *et al.*[26]	**POD 1**		**Week-1**
Daily step count [median (interquartile range)]		**Increase in steps/day**	
Cardiac surgery patients	53 (0–120)		133***
Thoracic surgery patients	393 (184–703)		272***

van Bakel *et al.*[34] data were not extracted as individual activity data for CABG patients not reported during admission.
CABG, coronary artery bypass grafting; CI, confidence interval; MET, metabolic equivalent; NR, not reported; POD, post-operative day; PT, physiotherapist.
*men vs. women, $P < 0.001$.
**POD1–POD5, $P < 0.001$.
***$P = 0.05$.

to use these devices as requested. In practice, it should, however, be anticipated that between 10% and 25% of participants may choose not to accept or adhere to consistent use of these devices. It is noteworthy that included studies did not report data exploring consumer perspectives on the use of wearable technologies and this represents an important area for further investigation. The identified studies

Table 5 Exercise and activity levels following hospital discharge

Author and outcome measure		**Time post-discharge**	
Gray *et al.*[29]		**Week 1**	**Week 3**
Daily steps, mean, SD (range)		1117 ± 824 (362–2889)	2861 ± 2357 (838–7849)
Light activity, min/day, mean, SD (range)		59.8 ± 39.3 (23–156)	89.4 ± 50.4 (37.2–209.5)
Moderate-to-vigorous activity min/day, mean, SD (range)		4.2 ± 5.1 (0.9–18.7)	14.8 ± 18.2 (1.1–55.8)
Sedentary time, h/day, mean, SD (range)		9.0 ± 2.2 (5.2–12.3)	6.8 ± 1.9 (3.0–9.2)
Thijs *et al.*[33]		**Week 1**	**Week 2**
Daily steps, median (range)			
Conventional surgery		1110 (739–10 195)	1832 (856–11 282)
Robot-assisted surgery		3715 (1637–6720)	4357 (1415, 7671)
Hauguel-Moreau *et al.*[30]		**Day 11**	**Day 13–14**
Daily step, mean, SD		1454 (145)	≥2000 (n.a.)
Cotton *et al.*[26]			**Day 28**
Steps/day median (25–75%)			
Cardiac surgery patients			2654 (1641–5103)
Thoracic surgery patients			2511 (2312–4607)
Increase in steps/day	**Day 14**	**Day 21**	
Cardiac surgery patients	100	−3	205
Thoracic surgery patients	190	108	−144

van Bakel *et al.*[34] data were not extracted as individual activity data for CABG patients not reported.

did not directly compare different activity trackers, so it is not possible to make recommendations about the relative merits of the different devices available on the market.

Only one study was identified that rigorously evaluated the accuracy of wearable activity trackers against a gold standard. Daligadu *et al.*[28] compared readings obtained from the Fitbit Flex™ against a criterion measure using manual counts of patient activity based on evaluating video recordings. This comparison found that the Fitbit Flex™ consistently reported a significantly higher step count and walking distance than the criterion measure, suggesting that the Fitbit Flex™ may be inaccurate.[28] Sushames *et al.*[35] found that Fitbit™ devices can underestimate step counts at slower walking speeds, indicating that this device may lack precision in clinical contexts. Jones *et al.*[36] compared both the Fitbit Flex™ and ActiGraph GT3X+™ triaxial accelerometer and showed a correlation when comparing step counts at slow speed and that as standard walking speeds are reached, the accuracy of the data improved. One systematic review, however, showed that Fitbit™ devices provided the most accurate measurement of step counts when compared with other consumer-directed wearable devices.[37]

The position on the body where the Fitbit™ device is worn also impacts on precision.[35,37] Puterman *et al.*[37] found that waist-worn Fitbit™ devices were somewhat accurate at self-paced or normal walking speeds but were more accurate at moderate to vigorous jogging speeds. Sushames *et al.*[35] found that wrist-worn accelerometers were not as accurate waist-worn devices. These findings indicate that in a clinical environment, if accurate measures of patient activity are required, it is preferable for patients to wear the device around their waist.

The use of wearable activity trackers to measure post-cardiac surgery exercise participation in acute care was evaluated in five studies. In the first week post-cardiothoracic surgery, only light activity is recommended. One study evaluated the use of artificial neural network analysis to summarize the data obtained from accelerometer devices.[5] This study found that the machine learning model could differentiate between sedentary activities and exercise participation and showed that immediately following surgery most patients were sedentary, spending most of their time lying in bed, but over their admission, the proportion of activity time increased.[5]

Gray *et al.*[29] found that patients' exercise intensity was measured as light to moderate in the first few weeks following acute care discharge, which is in line with recommendations.[8,10] As the immediate cardiac post-operative phase is the most critical period, where complications are most likely to arise, the results of these studies indicate that there is the potential to use wearable devices to promote participation in safe exercise and activity.[37] A recent study by van Bakel *et al.*[34] found that patients who had undergone cardiac surgery were more inactive than other patient cohorts admitted with ischaemic heart disease and that, in the first week following hospital discharge, many CABG surgery patients remained sedentary. This finding highlights the potential benefits of supplying patients with activity trackers and an online coaching intervention to increase patient participation in exercise in the first month following cardiac surgery.

Studies in this review used wearable triaxial accelerometers to document the normal trajectory of recovery and explore possible sex differences in exercise tolerance. Mungovan *et al.*[31] showed that over the course of an acute care admission, independent and physiotherapist-

Table 6 Association between inpatient activity levels and hospital length of stay, discharge destination, and readmissions

Author/variable	Patient outcomes		
Brown *et al.*[25]	**Hospital length of stay ≥ 7 days**	**Discharge to non-home location**	**Hospital readmission (12 months)**
Number of StepWatch™ steps on POD2, *Mdn*	424 vs. 90*	298 vs. 14.5*	Not reported
Diagnostic accuracy, AUC/ROC			
ActiGraph™	0.69–0.70	0.78–0.79	0.63–0.64
StepWatch™	0.74–0.75	0.76–0.78	0.71–0.73
Fitbit™	0.53–0.59	0.60–0.69	0.47–0.54
Johns Hopkins HLM Scale	0.59–0.72	0.73–0.80	0.51–0.63
Step thresholds (StepWatch™)			
100 steps, sensitivity (specificity)	53% (84%)	71% (75%)	62% (77%)
250 steps, sensitivity (specificity)	74% (68%)	83% (56%)	74% (56%)
500 steps, sensitivity (specificity)	87% (35%)	96% (29%)	91% (29%)
750 steps, sensitivity (specificity)	96% (15%)	100% (12%)	97% (12%)

Mungovan *et al.*[31]	Hospital length of stay
Strength of association between inpatient activity levels and hospital length of stay, mean (SD)	9 (3)
	Spearman's correlation, r
Physiotherapist-supervised activity	−0.65
Independent activity	−0.43
Overall activity	−0.62

Takahashi *et al.*[32]	Cardiac re-hospitalization	
	No readmission	**Readmission**
In-patient step count, mean (SD)	1297 (1232) vs.	2620 (1524)

AUC, area under the curve; HLM, highest level of mobility; HR, hazard ratio; POD, post-operative day; ROC, receiver operating curve.
*$P < 0.0001$.

supervised exercise increased and that men's exercise participation was consistently greater than women's participation. One limitation of this study is that there was no adjustment for pre-operative differences in exercise participation between men and women. In contrast, Brown *et al.*[25] found that women also had lower pre-operative activity levels and exercise tolerance, possibly reflecting the older age cohort of women who require cardiac surgery. Mansour *et al.*[38] suggest that the difference in physical activity performance can be due to a range of physiological and morphological differences. Women can experience more barriers to physical activity than men and a lack of confidence in their ability may restrict women from exercise participation in general.[39,40]

Implications for clinical practice and future research

The outcomes of this review found that activity levels in the immediate, acute post-operative period are important predictors of patients' recovery trajectory and acute health care utilization.[41,42] The review findings indicate that wearable activity trackers vary in accuracy; despite this, these devices may be useful in clinical practice as they can provide patients with a measure of their personal activity and progress. This information may be helpful in motivating patients to incrementally increase the distance they walk and their overall activity levels during their acute care admission. The availability of this activity data may also provide clinicians with a more objective measure of individual patients' progress. There is also the potential to use wearable devices to guide patients to gradually increase their activity levels following admission for cardiac surgery and ischaemic cardiac events.[34] To use these devices to their maximum potential and to obtain accurate activity data careful attention are needed on the placement of the device. To use these devices effectively in a clinical practice environment, it is important to consider placement when setting up the use of these devices with patients.

Future research could consider the use of wearable technologies as an objective measure for pain management, mobility, and patient's progress post-surgery coupled with the subjective measure of discussing these issues with patients. This review provides evidence that the use of wearable triaxial accelerometers is feasible with cardiac surgery patients and can be used to provide information about patients' activity levels and recovery trajectory.

Strengths and limitations

Strengths of this study include the breadth of literature that was reviewed, demonstrating that wearable devices are a useful tool to support the safety and activity monitoring of cardiac patients. Limitations of this study include that each study reported different primary outcomes and this heterogeneity in the outcome measures used precludes the potential to conduct a systematic review with meta-analysis of study results.

Conclusion

The findings of this systematic scoping review have shown a breadth of literature evaluating the use of wearable technologies for cardiac surgery patients. Observational studies showed that triaxial accelerometers can be integrated into the acute care environment and provide patients and staff with useful feedback about patients' activity levels and progress with their acute recovery goals. The wearable devices analysed in this study including activity/accelerometers showed that their use was acceptable to both patients and clinicians. Further research is needed to rigorously evaluate the accuracy of these devices in different patient cohorts and whether more widespread use of wearable technologies improves patient safety and experience of care.

Author contributions

J.E. screened and assessed the study eligibility for inclusion, performed the quality appraisals of included studies, extracted the study data, analysed the data, and drafted the original manuscript. A.F.H. and J.M. conceptualized the study, screened the studies for inclusion/exclusion, checked the data extraction, reviewed the drafts of the manuscript, and supervised the novice researcher. D.K. performed the database searches and quality appraisal of included studies, contributed to the analysis, and reviewed the manuscript drafts.

Supplementary material

Supplementary material is available at *European Journal of Cardiovascular Nursing* online.

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Data availability

Additional data are available on email request to the corresponding author.

References

1. Kanejima Y, Shimogai T, Kitamura M, Ishihara K, Izawa K. Effect of early mobilisation on physical function in patients after cardiac surgery: a systematic review and meta-analysis. *Int J Environ Res Public Health* 2020;**17**:7091.
2. Kaushik A, Patel S, Dubey K. Digital cardiovascular care in COVID-19 pandemic: a potential alternative? *J Card Surg* 2020;**35**:3545–3550.
3. Hannan AL, Harders MP, Hing W, Climstein M, Coombes JS, Furness J. Impact of wearable physical activity monitoring devices with exercise prescription or advice in the maintenance phase of cardiac rehabilitation: systematic review and meta-analysis. *BMC Sports Sci Med Rehabil* 2019;**11**:14.
4. Esmealy L, Allahbakhshian A, Gholizadeh L, Farshbaf Khalili A, Sarbakhsh P. Effects of early mobilization on pulmonary parameters and complications post coronary artery bypass graft surgery. *Appl Nurs Res* 2023;**69**:e151653.
5. Halfwerk FR, van Haaren JH, Klaassen R, van Delden RW, Veltink PH, Grandjean JG. Objective quantification of in-hospital patient mobilization after cardiac surgery using accelerometers: selection, use, and analysis. *Sensors (Basel)* 2021;**21**:1979.
6. Jacob P, Gupta P, Shiju S, Omar AS, Ansari S, Mathew G, *et al.* Multidisciplinary, early mobility approach to enhance functional independence in patients admitted to a cardiothoracic intensive care unit: a quality improvement programme. *BMJ Open Qual* 2021;**10**:e001256.
7. Schaller S, Anstey M, Blobner M, Edrich T, Grabitz SD, Gradwohl-Matis I, *et al.* Early, goal-directed mobilisation in the surgical intensive care unit: a randomised controlled trial. *Lancet* 2016;**388**:1377–1388.
8. Hong S, Milross M, Alison J. Physiotherapy mobility and walking management of uncomplicated coronary artery bypass graft (CABG) surgery patients: a survey of clinicians' perspectives in Australia and New Zealand. *Physiother Theory Pract* 2020; **36**:226–240.
9. Chen B, Xie G, Lin Y, Chen L, Lin Z, You X, *et al.* A systematic review and meta-analysis of the effects of early mobilisation therapy in patients after cardiac surgery. *Medicine (Baltimore)* 2021;**100**:e25314.
10. Santos PMR, Ricci NA, Suster ÉAB, Paisani DM, Chiavegato LD. Effects of early mobilisation in patients after cardiac surgery: a systematic review. *Physiotherapy* 2017;**103**:1–12.
11. Szylinska A, Listewnik M, Rotterm I, Ryl A, Kottis K, Mokrzycki K, *et al.* The efficacy of inpatient vs. home-based physiotherapy following coronary artery bypass grafting. *Int J Environ Res Public Health* 2018;**15**:2572.
12. Ashur C, Cascino T, Lewis C, Townsend W, Sen A, Pekmezi D, *et al.* Do wearable activity trackers increase physical activity among cardiac rehabilitation participants? A systematic review and meta-analysis. *J Cardiopulm Rehabil Prev* 2021;**41**:249–256.
13. Vogel J, Auinger A, Riedi R, Kindermann H, Helfert M, Ocenasek H. Digitally enhanced recovery: investigating the use of digital self-tracking for monitoring leisure time physical activity of cardiovascular disease (CVD) patients undergoing cardiac rehabilitation. *PLoS One* 2017;**12**:e0186261.
14. Gierisch JM, Goode AP, Batch BC, Huffman KN, Hall KS, Hastings SN, *et al. The Impact of Wearable Motion Sensing Technologies on Physical Activity: A Systematic Review.* Washington (DC): Department of Veterans Affairs (US); 2015.
15. Amin T, Mobbs R, Mostafa N, Sy L, Choy W. Wearable devices for patient monitoring in the early postoperative period: a literature review. *mHealth* 2021;**7**:50.
16. van der Meij E, van der Ploeg H, van den Heuvel B, Dwars BJ, Jeroen WJH, Jaap Bonjer MH, *et al.* Assessing pre- and postoperative activity levels with an accelerometer: a proof-of-concept study. *BMC Surg* 2017;**17**:56.
17. Ghomrawi HM, Baumann LM, Kwon S, Hebal F, Hsiung G, Williams K, *et al.* Using accelerometers to characterize recovery after surgery in children. *J Pediatr Surg* 2018;**53**:1600–1605.
18. Munn Z, Peters MDJ, Stern C, Tufanaru C, McArthur A, Aromataris E. Systematic review or scoping review? Guidance for authors when choosing between a systematic or scoping review approach. *BMC Med Res Methodol* 2018;**18**:143.
19. Peters M, Godfrey C, Khalil H, McInerney P, Parker D, Soares C. Guidance for conducting systematic scoping reviews. *Int J Evid Based Healthc* 2015;**13**:141–146.
20. Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, *et al.* PRISMA extension for scoping reviews (PRISMAScR): checklist and explanation. *Ann Intern Med* 2018; **169**:467–473.
21. National Library of Medicine. Medical Subject Headings. 2019. Available at: http://www.nlm.nih.gov/mesh/meshhome.html.
22. Joanna Briggs Institute [JBI]. Quality Appraisal Checklists. https://jbi.global/critical-appraisal-tools. Accessed July 2022.
23. National Health and Medical Research Council (NHMRC). NHMRC levels of evidence and grades for recommendations for developers of guidelines. 2009. Available at: http://www.nhmrc.gov.au/sites/default/files/images/NHMRC%20Levels%20and%20Grades%20(2009).pdf.
24. Covidence. Better Systematic Review Management. 2022. Available at: www.covidence.org.
25. Brown H, Yanek L, Healy R, Tsay T, Di J, Goeddel L, *et al.* Comparing three wearable accelerometers to measure early activity after cardiac surgery. *JTCVS Open* 2022;**11**:176–191.
26. Cotton JL, Abbitt D, Carmichael H, Iguidbashian J, Suarez-Pierre A, Meguid RA, *et al.* Returning to baseline daily ambulation after cardiothoracic surgery. *Videoassist Thorac Surg* 2022;**7**:23.
27. Cook DJ, Thompson JE, Prinsen SK, Dearani JA, Deschamps C. Functional recovery in the elderly after major surgery: assessment of mobility recovery using wireless technology. *Ann Thorac Surg* 2013;**96**:1057–1061.
28. Daligadu J, Pollock C, Carlaw K, Chin M, Haynes A, Thevarajah Koral T, *et al.* Validation of the Fitbit Flex in an acute post-cardiac surgery patient population. *Physiother Can* 2018;**70**:314–320.
29. Gray E, Smith C, Bunton R, Skinner M. Perceptions and experiences of engaging in physical activity following coronary artery bypass graft surgery. *Physiother Theory Pract* 2022; **38**:2841–2855.

30. Hauguel-Moreau M, Naudin C, Lee N'Guyen L, Squara P, Rosencher J, Makowski S, *et al.* Smart bracelet to assess physical activity after cardiac surgery: a prospective study. *PLoS One* 2020;**15**:e0241368.
31. Mungovan S, Singh P, Gass G, Smart N, Hirschhorn A. Effect of physical activity in the first five days after cardiac surgery. *J Rehabil Med* 2017;**49**:71–77.
32. Takahashi T, Kumamaru M, Jenkins S, Saitoh M, Morisawa T, Matsuda H. In-patient step count predicts re-hospitalisation after cardiac surgery. *J Cardiol* 2015;**66**:286–291.
33. Thijs A, Fresiello L, Oosterlinck W, Sinnaeve P, Rega F. Assessment of physical activity by wearable technology during rehabilitation after cardiac surgery: explorative prospective monocentric observational cohort study. *JMIR Mhealth Uhealth* 2019;**7**:e9865.
34. van Bakel BMA, de Koning IA, Bakker EA, Pop GAM, Cramer E, van Geuns R-JM, *et al.* Rapid improvements in physical activity and sedentary behavior in patients with acute myocardial infarction immediately following hospital discharge. *J Am Heart Assoc* 2023;**12**:e028700.
35. Sushames A, Edwards A, Thompson F, Dermott R, Gebel K. Validity and reliability of Fitbit Flex for step count, moderate to vigorous physical activity and activity energy expenditure. *PLoS One* 2016;**11**:e0161224.
36. Jones D, Crossley K, Dascombe B, Hart H, Kemp J. Validity and reliability of the Fitbit Flex and ActGraph GT3X+ at jogging and running speeds. *Int J Sports Phys Ther* 2018;**13**:860–869.
37. Puterman E, Pauly T, Ruissen G, Nelson B, Faulkner G. Move more, move better: a narrative review of wearable technologies and their application to precision health. *Health Psychol* 2021;**40**:803–810.
38. Mansour G, Kacem A, Ishak M, Grelot L, Ftaiti F. The effect of body composition on strength and power in male and female students. *BMC Sports Sci Med Rehabil* 2021;**13**:150.
39. Ubeda-Colomer J, Devis-Devis J, Ginis K. Gender differences in theory-based predictors of physical activity in university students with disabilities. *Rev Latinoam Psicol* 2020;**52**:141–148.
40. Rosenfeld C. Sex-dependent differences in voluntary physical activity. *J Neurosci Res* 2017;**95**:279–290.
41. Nicolella D, Torres-Rondam L, Saylor K, Schelling X. Validity and reliability of an accelerometer-based player tracking device. *PLoS One* 2018;**13**:e0191823.
42. Tariq M, Khan A, Khalid Z, Farheen H, Siddiqi F, Amjad I. Effect of early ≤ 3 mets (metabolic equivalent of tasks) of physical activity on patient's outcome after cardiac surgery. *J Coll Physicians Surg Pak* 2017;**27**:490–494.