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Original Article

Patient-centred measurement of recovery from day-case surgery using wrist worn accelerometers: a pilot and feasibility study*

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Summary

This pilot and feasibility study evaluated wrist-worn accelerometers to measure recovery from day-case surgery in comparison with daily quality of recovery-15 scores. The protocol was designed with extensive patient and public involvement and engagement, and delivered by a research network of anaesthesia trainees. Forty-eight patients recruited through pre-operative assessment clinics wore wrist accelerometers for 7 days before (pre-operative) and immediately after elective surgery (early postoperative), and again at 3 months (late postoperative). Validated activity and quality of recovery questionnaires were administered. Raw accelerometry data were archived and analysed using open source software. The mean (SD) number of valid days of accelerometer wear per participant in the pre-operative, early and late postoperative periods were 5.4 (1.7), 6.6 (1.1) and 6.6 (1.0) days, respectively. On the day after surgery, Euclidian norm minus one (a summary measure of raw accelerations), step count, light physical activity and moderate/vigorous physical activity decreased to 57%, 47%, 59% and 35% of baseline values, respectively. Activity increased progressively on a daily basis but had not returned to baseline values by 7 days. Patient questionnaires suggested subjective recovery by postoperative day 3 to 4; however, accelerometry data showed that activity levels had not returned to baseline at this point. All activity measures had returned to baseline by 3 months. Wrist-worn accelerometery is acceptable to patients and feasible as a surrogate measure for monitoring postoperative recovery from day-case surgery. Our results suggest that patients may overestimate their rate of recovery from day-case surgery, which has important implications for future research.

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Introduction

The identification and measurement of outcomes from surgery and anaesthesia is an established priority for research in peri-operative medicine [1]. Progress and setbacks after discharge are monitored commonly by telephone calls, although these are labour intensive and contingent on the patient being contactable [2]. Further more, even daily inquiries lack granularity at a time when the patient's condition may be changing rapidly. Wearable activity monitors are used commonly for self-monitoring of exercise and might be useful to describe recovery at home following discharge from hospital. Accelerometers have been used previously in cohort studies including 100,000 participants in a study by Doherty et al. [3] and 4000 participants in a study by Menai et al. [4]. Typically, a wearable activity monitor uses a tri-axial accelerometer to measure acceleration along three axes, which can then be analysed using computer algorithms and represented as activities. These can be count-based and device specific (e.g. step count), describe sedentary or active time in terms of energy expenditure (e.g. vigorous/moderate/low intensity activity), measure sleep quality and quantity, or characterise complex activity using machine learning techniques [5]. Notably, time to mobilisation and sleep quality are endpoints recommended by the standardised endpoints in peri-operative medicine (StEP) initiative for the measurement of patient comfort in peri-operative research [6]. While the activity of hospital in-patients is known to be low [7, 8], mobilisation after discharge is not well characterised.

Accelerometers for the assessment of recovery (AFAR) is a pilot and feasibility study designed and run by the trainee South West Anaesthesia Research Matrix (SWARM) [9]. This study was undertaken in collaboration with OpenLab, a laboratory specialising in human computer interaction and ubiquitous computing at Newcastle University. We used wrist-worn accelerometers to record raw acceleration data and open source software for analysis. This approach allows: reproducibility of research; re-analysis; data aggregation [10]; researcher control of the raw data; and can reduce costs [11]. An example is the development of an open source algorithm for sleep analysis using raw accelerometer data from the Menai et al. [4], applied later to archived data [12].

We asked the following research questions: first, are wrist-worn accelerometers an acceptable and feasible way to measure recovery from day-case surgery, and could this method be deployed at scale across a research network?; and second, do available open source algorithms show utility in representing the activity (including sleep) of patients recovering from day-case surgery, and is this comparable with results of the quality of recovery-15 score [13]? We also aimed to demonstrate the capability of SWARM to conduct a clinical trial while giving research experience to trainees in anaesthesia.

Methods

Ethical approval for the study protocol was gained. Written informed consent was provided by all patients and included agreement to archiving of their de-identified raw accelerometery data in a secure data repository. This was a pilot study run at two SWARM sites: University Hospital Plymouth NHS Trust, a large regional teaching hospital and tertiary referral centre; and Royal Cornwall Hospitals NHS trust, a busy district general hospital. We aimed to recruit approximately 50 patients between the two sites; this sample size was based on a previous similar study [2], group experience and guidelines for pilot study size [14].

Our pilot study was developed with patient and public involvement and engagement including a questionnaire-based scoping survey (see online Supporting Information, Appendix S1) distributed at the Royal Cornwall Hospitals NHS Trust pre-assessment clinic with the aim to identify: the level of technology awareness and use among our patient cohort; the acceptability of wearing a device; and how important movement and activity is to our local patient cohort in the (anticipated) recovery period. All participating patients were invited to complete a feedback questionnaire (see online Supporting Information, Appendix S1) during their involvement with the study. Finally, a semi-structured focus group session was held with a convenience sample of five study participants and three members of the research team to explore in-depth patient experience of the study, and to discuss plans for a further study.

Adult patients (aged > 18 years) scheduled for day-case surgery under general or neuraxial anaesthesia were eligible for inclusion in the study. Patients were still included in the study if they had a one-night planned admission for social reasons or a one-night unplanned admission. We did not study patients who were unable to consent and/or having surgical procedures or other factors likely to limit mobility (e.g. knee arthroscopy).

Participants wore an AX3 tri-axial accelerometer (Axivity; Newcastle upon Tyne, UK) on their dominant wrist for three wear periods (Fig. 1). These were: 7 consecutive days pre-operatively (pre-operative period); the first 7 postoperative days (early postoperative period); and a

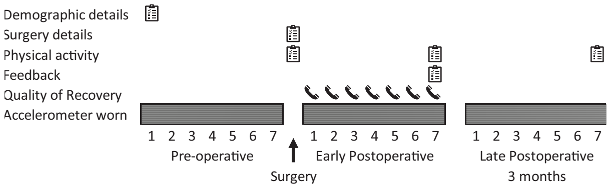

Figure 1 Schedule of data collection for 48 patients undergoing elective day-case surgery who wore the AX3 tri-axial accelerometer on their dominant wrist over three 7-day wear periods: pre-operative (baseline); early postoperative (first 7 postoperative days); and late postoperative (3 months). In addition to recording of baseline characteristics and surgical data, questionnaires were administered on the day of surgery, daily for 7 days after surgery and at the end of the study.

further 7 consecutive days approximately 3 months after surgery (late postoperative period). The logistical processes for distribution and return of the accelerometers are detailed in Table 1. We aimed to acquire activity profiles at baseline, during an initial recovery period and following full recovery from surgery. The AX3 device was pre-programmed to record accelerations between −8 and +8 g for 7 days at a sampling frequency of 100 Hz to give optimal sampling frequency to battery time ratio. These are the default settings, have appropriate sensitivity to movement (accelerations) of the study population and have been used in other studies with these devices [3, 15]. Raw accelerometery data were downloaded and de-identified by the research team before transfer to a secure file-sharing area hosted by Newcastle University.

Baseline characteristics and operation details were collected to define the group characteristics. The General Practice Physical Activity Questionnaire [16] (GPPAQ) and a modified version of the Duke Activity Status Index (DASI) [17] were completed at the end of each wear period (see online Supporting Information, Appendix S1). Completion of the questionnaires was supervised directly in the pre-assessment clinic, encouraged by telephone call in the early postoperative period and without reminder in the late postoperative period. Modifications to the DASI included minor language adjustments for a UK patient population and the omission of the question relating to sexual activity. During the early postoperative period, the quality of recovery-15 score [13] was measured daily by a questionnaire completed by telephone. Figure 1 depicts the timeline of data collection and study outcome measures recorded during the peri-operative journey.

Summary statistics and graphs were used to describe the data; inferential statistics were not used as this was a pilot study. A flowchart was developed from the consolidated standards of reporting trials (CONSORT) guidelines for pilot studies [18] to display feasibility results and recommendations for best practice in accelerometer-based research [19]. The post-participation focus group session was transcribed verbatim and analysed thematically using NVivo version 12 software (QSR International (UK) Limited, Daresbury, UK). Summarisation of free-text

Table 1 Procedure for distribution and return of accelerometers and the retrieval of data for each of the three 7-day wear periods. Data from each wear period were downloaded locally, de-identified, labelled with a study number, and uploaded to the Newcastle University secure file-sharing site for analysis.

Wear period	Activity	Procedure
Pre-operative	Distribution and deployment	Accelerometer either: -given directly to the participant at recruitment if their surgery fell within 2 weeks of recruitment; or -sent by post.
	Return and data retrieval	Participant brings the accelerometer with them on the day of surgery. A member of the research team meets them, downloads accelerometer data and recharges device using designated laptop
Early postoperative	Distribution and deployment	Accelerometer returned to the patient with instructions to re-commence wearing on leaving the hospital
	Return and data retrieval	Stamped addressed envelope supplied for return after 7 days wear. Data downloaded by researcher in Plymouth onto designated laptop
Late postoperative	Distribution and deployment	Accelerometer sent by post (may not be the same device)
	Return and data retrieval	Stamped addressed envelope supplied for return after 7 days wear. Data downloaded by researcher in Plymouth using designated laptop

comments on feedback questionnaires was conducted manually.

Accelerometery data were processed in R using the software package GGIR (Vincent T van Hees, version 1.11-0, CRAN Archive, https://cran.r-project.org/web/packages/GGIR/). Python 3.8 libraries (www.python.org) 'numpy', 'pandas', 'statsmodels', 'sklearn', 'matplotlib' and 'seaborn' were used for analyses and graphs. Data extracted between the start and the end of recording were retained for analysis, yielding a maximum of seven consecutive 24-h recording periods. If any records exceeded 168 h, we discarded the surplus data. Calibration error was estimated based on static periods in the data and corrected if necessary (calibration correction range = 0.8–10.0 mg, mean correction = 2.5 mg [20]).

Non-wearing time was detected by a tuned classifier using established methods [21, 22]. The classifier aimed to distinguish genuine non-wear (i.e. device removal for showering or sleep) from immobility during rest or sleep. Subject to contextual information from a wider 60-min window, a 15-min block of data was classified as a non-wear period if two out of three axes absolute value was <50 mg or their SD < 13.0 mg ($1\ \mathrm{mg} = 0.00981\ \mathrm{m}^{-2}$) [20]. We excluded these non-wearing data blocks for all wear periods and did not impute the accelerometer data. Days were defined as up to seven consecutive 24-h periods from the beginning of the accelerometer recording. A valid day was defined as having a minimum of wearing time of 10 h, a criterion which is used commonly in physical activity and health assessment studies [23, 24]. Patients with at least one valid day per wear period were included in the analysis of accelerometry.

The Euclidean norm minus one, where r_i is the vector magnitude at the time point i, is shown below:

$$r_i = \sqrt{x_i^2 + y_i^2 + z_i^2} - 1000$$

This was used to quantify the acceleration related to the movement registered and is expressed in mg [21]. The Euclidean norm minus one subtracted a fixed offset value of 1 g at each time point to remove gravity [21] and was averaged over 5-s epochs. Negative values were rounded to zero to reduce bias and error. Using the dominant wrist, periods of physical activity were classified into: sedentary (<50 mg); light (50–110 mg); and moderate/vigorous physical activity (>110 mg) (see online Supporting Information, Appendix S1). Sleep periods were detected using a validated algorithm [11]. For sleep period analysis, a valid day was defined as having at least 16 h of wearing time. Sleep duration (the interval between sleep onset time and end of sleep awakening time) and sleep efficiency (the proportion of that time actually asleep) were calculated. Eighty-five percent is considered normal sleep efficiency. To calculate the number of steps we resampled the accelerometer data to 15 Hz in R (version 3.6) using the software package GGIR. Step counts were then calculated using an algorithm suitable for wrist-worn accelerometers [25, 26].

Results

We distributed 100 scoping questionnaires of which 56 were completed and returned. Full results are available in online Supporting Information, Appendix S1. The majority of respondents (53/56) were willing to wear an activity monitor for research purposes and expressed a preference for wearing it on their dominant wrist; therefore, this site was used in the study. Activity-related concerns ranked second among aspects of recovery that were of greatest importance to respondents.

Screening was pragmatic and based on the availability of a SWARM investigator in the pre-assessment clinic. Eighty-nine eligible patients were approached between November 2018 and May 2019 of whom 63 agreed to take part and 48 were studied (Fig. 2). The baseline characteristics of participating patients are summarised in Table 2.

Wear compliance was good, although 10 patients were unable to complete the full 7-day pre-operative wear period as their surgery fell within a week of recruitment. The mean (SD) number of valid days of accelerometer wear per participant in the pre-operative, early and late postoperative periods were 5.4 (1.7), 6.6 (1.1) and 6.6 (1.0) days, respectively. No serious adverse events occurred. One participant developed a localised rash under the watch strap. Usable accelerometry data were collected during the majority of wear periods (Fig. 2). Some data were lost due to battery failure affecting several devices. Defective devices were replaced by the manufacturer and the problem resolved.

Forty-seven patients returned their early postoperative feedback questionnaires. Patients were asked to score the AX3 device (minimum 0, maximum 10) for comfort and appearance. The mean (SD) scores for comfort and appearance were 9.0 (1.3) and 8.8 (1.7), respectively. We were interested to learn if patients were worried about having their activity monitored (e.g. feeling that it was an invasion of their privacy), but no concerns in this regard were reported. Practical concerns reported included the need to keep the device clean and dry at work or when washing. The most common complaints

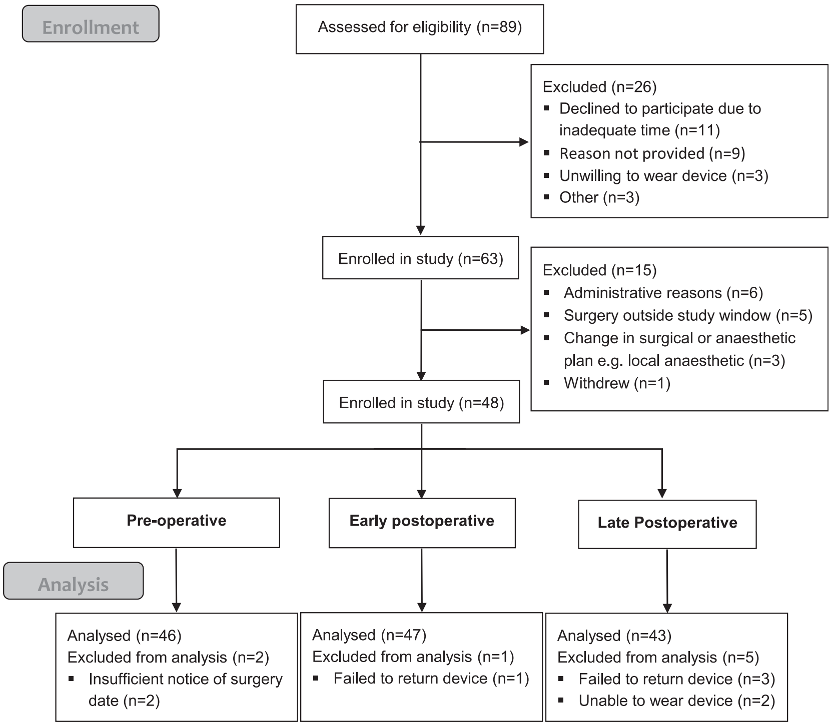

Figure 2 Recruitment, retention and accelerometer data collection for 48 patients undergoing day-case surgery including outcomes required in the CONSORT extension for reporting pilot studies [18] and following recommendations for best practice in reporting research using physical activity monitors [19].

were that the strap could catch clothing (reported five times) and that skin could become itchy/sweaty under the strap (reported three times). Explanations for temporary removal of the device included: two patients who could not wear the device at work; two patients preferred not to wear it at night; one patient took the device off when re-admitted overnight to hospital during the first postoperative week; and one patient removed the device due to the development of a rash under the strap.

Postoperative median (IQR [range]) quality of recovery-15 scores showed an upward trend during the first postoperative week, increasing from 123 (105–138 [76–150]) at 24 h to 145 (132–150 [100–150]) at 7 days (Fig. 3). The proportion of patients achieving the highest possible score at 24 h, 48 h and 7 days was 1/44, 2/41 and 11/43, respectively, which is a pattern consistent with other studies [27].

Activity profiles during the three wear periods are shown in Figures. 4 and 5. Euclidean norm minus one and step counts showed similar profiles during the pre-operative and late postoperative wear periods with a recovery trajectory during the first 7 postoperative days. Physical activity did not return to baseline during the week after surgery but had done so by 3 months. Moderate/vigorous physical activity was reduced markedly after surgery; light physical activity was also reduced but not to the same degree (Fig. 5).

Scores for the quality of recovery-15 sleep question were low after surgery and then normalised over several days (Fig. 6). However, this trend was not reflected in the accelerometer-derived metrics for sleep duration and efficiency (Fig. 7).

The GPPAQ and modified DASI were completed by all participants at the end of the pre-operative period, usually under direct supervision on the day of surgery. Despite a telephone reminder, 12 out of 96 questionnaires were not returned or were unusable after the early postoperative period. This increased to 22 out of 96 in the late postoperative period when the reminder was included in the accelerometer packaging. Self-reported activity scores decreased after surgery and had returned to baseline by 3 months (Table 3).

Our post-participation focus group included five study participants (mean (SD) age 63 (12) years), three male participants) of whom two were in full-time employment, one was semi-retired and two fully retired. Wearing the accelerometer was reported to be acceptable by all patients, although some were concerned they might damage the devices while working during the pre-operative phase. Reported anxieties related predominately to surgery

Table 2 Characteristics of 48 patients undergoing elective day-case surgery and enrolled to wear wrist-based accelerometers pre- and postoperatively. Values are mean (SD), number or median (IQR [range]). Self-assessed baseline physical activity was categorised by the General Practice Physical Activity Questionnaire (GPPAQ).

Age; years	55 (17)
Sex; female	28
BMI; kg.m^{-2}	29 (27–34 [21–48])
ASA physical status	
1	11
2	27
3	10
Baseline physical activity	
Active	10
Moderately active	10
Moderately inactive	6
Inactive	22
Surgical speciality	
General	17
Urology	12
Gynaecology	7
Breast	6
Head and neck	4
Orthopaedic	1
Plastics	1
Duration of surgery; min	86 (37)
Duration of stay in recovery area; min	57 (36)
Overnight stay	
Yes (planned)	1
Yes (unplanned)	4*
No	43

*Causes of unplanned admission were: surgical complication (n = 1); slow recovery (n = 1); and pain (n = 2).

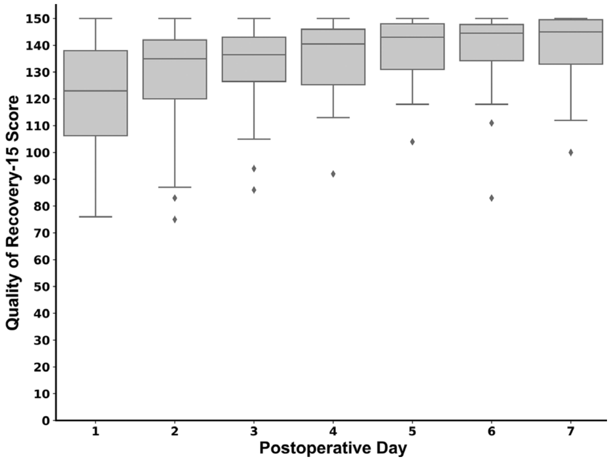

Figure 3 Daily quality of recovery-15 scores of 48 patients after elective day-case surgery. Boxes represent median and interquartile range, whiskers are 5th and 95th centiles. Values outside 1.5 times the interquartile range above the upper quartile or below the lower quartile are shown as outliers.

and the underlying diagnosis. Suggestions for extending the scope of accelerometry included: improved postoperative monitoring at home; encouraging patients to increase their activity; and as an aid to weight loss. Our thematic analysis is summarised in Table 4.

Discussion

We have demonstrated that wearable accelerometry is acceptable to patients and feasible as a surrogate measure for monitoring postoperative recovery from day-case surgery. As an objective measure of activity, it may have advantages over questionnaires, especially if these have not been validated [28]. Our attempts to involve patients were successful and useful. Their input informed the design of the protocol (e.g. device worn on the dominant wrist), explained missing data (e.g. fear of device damage, workplace issues) and gave context (e.g. prevalence of cancer fears and anxiety about surgery). Patients also made helpful suggestions for routinely integrating accelerometry into peri-operative recovery (e.g. self-monitoring, motivation and remote support).

This study was delivered by the SWARM network, which offers anaesthesia trainees participation in meaningful research projects. Our trainees achieved the National Institute of Academic Anaesthesia's (NIAA) research engagement objective of becoming 'research experienced' [29], undertaking all stages of the project from funding application, patient recruitment, data collection and roles of principal and chief investigator, thereby preparing them to become engaged participants in a research-active speciality.

We have demonstrated that derivatives of unsupervised home accelerometry such as the Euclidean norm minus one and step count, describe a recovery profile consistent with the resource-intensive daily application of a validated recovery measure (quality of recovery-15). The greatest impact of surgery on activity was the reduction in moderate/vigorous physical activity to 35% of baseline, which is biologically plausible and intuitive. The lesser effect on light physical activity (reduced to 59% of baseline) may reflect that those activities are less painful or physiologically disturbing in the context of recent surgery. However, all activity measures were below baseline values throughout the first postoperative week, even though patients reported

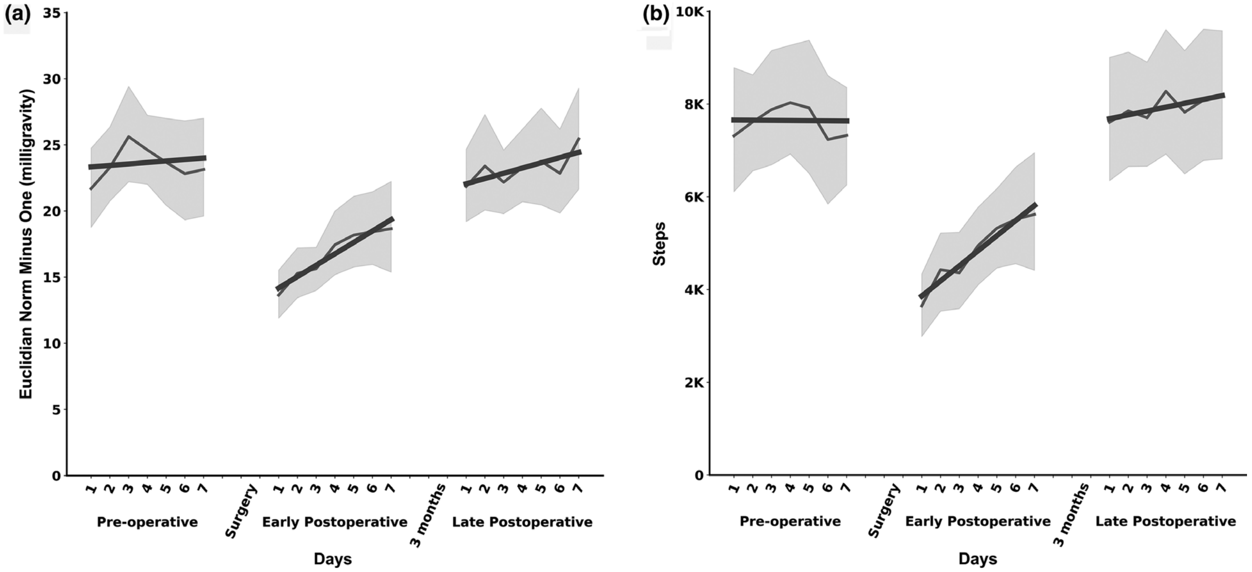

Figure 4 Accelerometry derivatives of 48 patients after elective day-case surgery. (a) total accelerations expressed as Euclidean norm minus one (milligravity.day^{-1}) and (b) step count. Data were collected over three 7-day wear periods: pre-operative (baseline); early postoperative (first 7 postoperative days); and late postoperative (3 months). Thin lines represent the mean value for the group, the shaded area shows the 95%CI of the population mean and the thick regression line highlights the trend in group results with time.

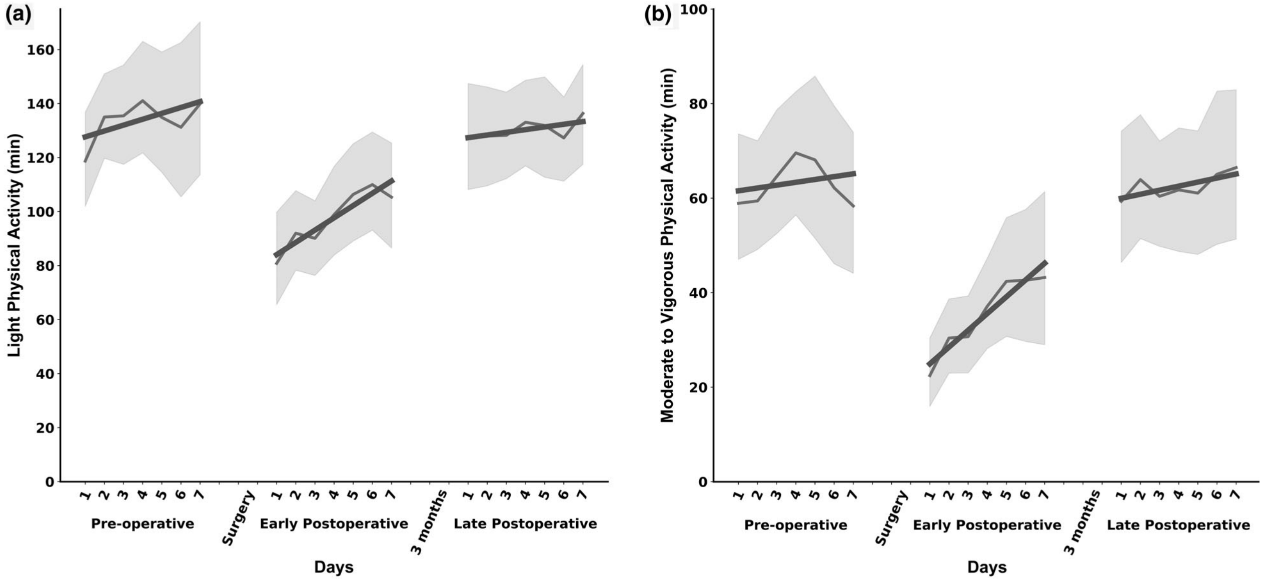

Figure 5 Accelerometry derivatives of 48 patients after elective day-case surgery. (a) duration of light physical activity and (b) moderate or vigorous physical activity. Data were collected over three 7-day wear periods: pre-operative (baseline); early postoperative (first 7 postoperative days); and late postoperative (3 months). Thin lines represent the mean value for the group, the shaded area shows the 95%CI of the population mean and the thick regression line highlights the trend in group results with time.

themselves recovered after 3 days. This implies that accelerometry can detect degrees of functional impairment that patients do not consider important, or that the quality of recovery-15 score is unable to detect. Alternatively, patients may have been feeling fully recovered but obeying physician or self-imposed limits on activity. Similar

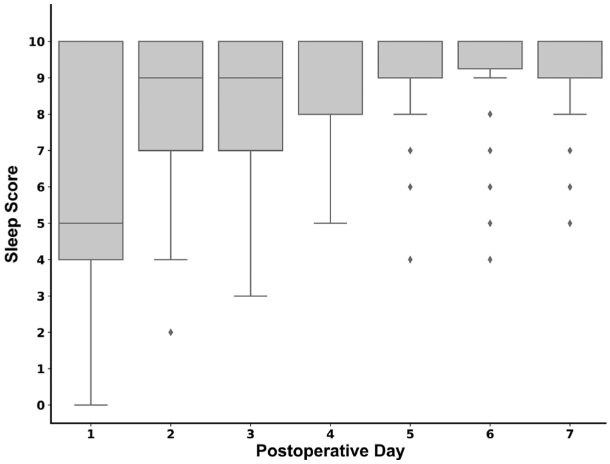

Figure 6 Sleep score of 48 patients after elective day-case surgery. Boxes represent median and interquartile range, whiskers are 5th and 95th centiles. Values outside 1.5 times the interquartile range above the upper quartile or below the lower quartile are shown as outliers.

overestimation of self-reported activity has been observed in patients having bariatric surgery [30].

Each wear period was 1 week in duration and we observed changes in the accelerometry derivatives throughout the early postoperative period suggesting that this is the optimal measurement time frame. In the pre-operative and late postoperative periods, the initial 2 or 3 days was consistent with the remainder of the 7-day-period; therefore, is potentially not necessary to collect data for an entire week to characterise a patient's baseline function or to confirm their return to normal.

The inconsistency between responses to the quality of recovery-15 sleep question and our quantification of night-time sleep duration and efficiency was unexpected and requires further investigation. Movement-derived indices of sleep may not reflect what patients perceive as sleep quality. Advanced signal processing of accelerometry data is a development field with inconsistent performance of candidate analyses [31]. Extraction of multiple mobility indices and their subsequent combination may be useful [32]. Emerging analytics may yield specialist data, for example, in orthopaedic surgery, where bouts of shortened stepping may indicate joint pain. However, the quantification of posture (sitting, lying, standing) and purposeful activity remains experimental with variable results [31].

Other studies have used postoperative accelerometry to: describe recovery of mobility after lung surgery [33]; demonstrate the ineffectiveness of interventions designed to improve patient mobilisation after prolapse surgery [34]; and quantify the utility of a behavioural support tool after

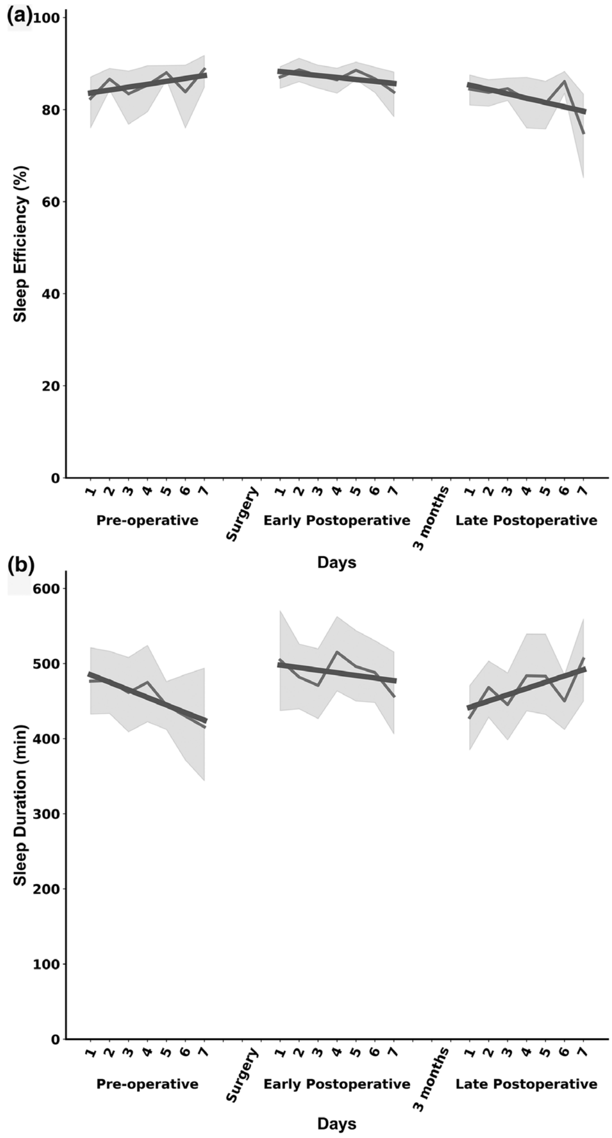

Figure 7 Accelerometry derivatives of 48 patients after elective day-case surgery. (a) sleep efficiency and (b) night-time sleep duration. Data were collected over three 7-day wear periods: pre-operative (baseline); early postoperative (first 7 postoperative days); and late postoperative (3 months). Thin lines represent the mean value for the group, the shaded area shows the 95%CI of the population mean and the thick regression line highlights the trend in group results with time.

abdominal cancer surgery [35]. Bisgaard et al. evaluated hip-worn accelerometry postoperatively for quantifying physical activity and sleep in a small group of patients and volunteer controls, and reported a clinically acceptable correlation with physical activity and an unvalidated self-assessment of sleep [36]. However, methodology remains heterogeneous. A recent review noted that "*...future*

Table 3 Results of physical activity questionnaires in 48 patients undergoing day-case surgery assessed using modified Duke Activity Status Index (DASI) and General Practice Physical Activity Questionnaire (GPPAQ). Values are number and median (IQR [range]).

	Pre-operative	Early postoperative	Late postoperative
Modified DASI			
Valid	48/48	43/48	39/48
Missing	–	5*	9*
Score	10 (8–12 [4–12])	8 (6–9 [2–12])	11 (7–9 [4–12]
GPPAQ			
Valid	48/48	41/48	35/48
Missing	–	7	13
Active	10	5	8
Moderately active	10	10	4
Moderately inactive	6	6	6
Inactive	22	20	17

*Includes two participants who inserted numeric values rather than crosses when completing the modified Duke Activity Status Index.

research would benefit from consistency in measurement methods and agreement on the most crucial types of outcomes to measure" [37].

Commercial activity monitors for domestic use typically report a limited range of accelerometer-derived activities using proprietary and non-disclosed algorithms which are subject to change. Raw data are discarded and there are ethical and data protection issues [38]. Further, there are a plethora of devices available which is a limiting factor; a systematic review of accelerometer use to measure physical activity in hospital (including 10 studies in the postoperative setting) identified that 17 different devices were used, and concluded it was not possible to aggregate data for meta-analysis due to the heterogeneity of the measured outcomes [39]. Sharing raw data permits pooled analysis, an approach pioneered with pharmacokinetic data shared through the open TCI initiative (www.opentci.org). Our commitment to open-source software complies with earlier recommendations [40] and our patients agreement to open-data archiving allows this to be explored with future novel algorithms.

Accelerometers have seen increasing use to document mobilisation after surgery and evaluate measures intended to improve it. Standardisation of outcome measures is recommended [41] (although the methods of measurement are not specified) and we used a validated recovery measure compliant with that initiative [13]. Possible roles for accelerometry in the peri-operative period are summarised in Table 5.

Moving beyond the descriptive, activity monitoring could be integrated into care pathways to identify poor progress or as part of an intervention. Full mobilisation after laparoscopic cholecystectomy takes over a week and may be modestly accelerated by combining motivational accelerometry with personalised advice on exercise [42]. Recovery from major surgery is enhanced by ambulation, and step counts on the first postoperative day are inversely correlated with duration of hospital stay [43]. This suggests a testable hypothesis that feedback to patients of their objectively-quantified activity might reduce their time in hospital. However, patient engagement with technology-derived advice cannot be taken for granted. When a cohort of 79,953 patients was invited to share their fitness-tracker data with their healthcare provider, less than 1% did so. Further, the investigators concluded "*…patients most at risk for poor health outcomes are least likely to share personal fitness-tracker data*" [44]. Our focus group analysis offers some insights into the complex personal world in which individual surgical episodes are embedded and suggests the importance of continued attention to the social science and qualitative dimensions of future interventions. Patients at a Dutch academic medical centre were reluctant to participate in accelerometry monitoring after surgery and in some cases sleep monitoring was limited by discomfort from the hip accelerometer [24]. We avoided this type of problem with public engagement in the design of our protocol.

We have demonstrated effective peri-operative deployment of accelermotry by a trainee research network. Our experience suggests accelerometry has the potential to support and monitor patient mobilisation. The information generated could evaluate activity-related interventions either by motivating patients to exercise more or by identifying a subset of patients who progress less well than

Table 4 Results of qualitative analysis of post-participation feedback focus group, organised into 'overarching themes', 'sub-themes' and 'codes', including quotes as examples of text within each code.

Overarching themes	Sub-themes	Codes	Quotes
AX3 wrist-worn accelerometer	Practicality and wearability	-Comfort -Appearance -Occupational considerations -Concerns: getting device wet/dirty/damaged	*"Initially I was conscious that I had it on, not to get it to dirty, because you have to keep it quite tight on your wrist otherwise it slips around and what have you, and I can suggest some of the places that I put my hand on a livestock farm"* *"When I was dealing with patients I was very much aware that it was there. Not that it was not a big deal, it wouldn't cause me to stop wearing it in the future"*
	Current model functionality and potential future modifications	-Current state functionality and seeking clarification of what it can measure (sleep, pain, blood pressure) -To view activity count -Heart rate analysis -Wireless connectivity	*"I wasn't totally sure what the watch was measuring whilst it was on my wrist. . .could it register pain? Is it like a pedometer when you go walking and it counts your paces?"*
	Burden and awareness	-Burden -Awareness -'Big Brother' effect -Effect on activity	*"I can honestly say for myself there was nothing to it to be honest, you put it on and forget it was there; I wore it 99% of the time"* *"I have to say I did find it a little bit irritating, well just because the strap; the tongue of it kept undoing itself"*
	Accuracy and misrepresentation	-Seasonal differences in activity	*"I'd like to point that out just in case it hadn't been noticed, in the winter you do less, come the summer, if we had the operation in the summer, I'm sure we'd all get out and about a lot more"*
Peri-operative experience	Relating to having an operation	-Apprehension about the operation -Activity levels and attitude to activity around an operation -State of mind and recovery -Coping with peri-operative anxiety	*"I think the only thing you think of before your op, is your op."* *"So let me say that you're not in the same state of mind before an operation"* *"But don't forget, well I guess we've all had cancer. . . I wake up first thing in the morning and well you don't think about it but it never leaves you, so you have got that shall I say, that in your head, you carry around with you most of the time"*
	Related to the underlying diagnosis	-Anxiety/awareness about underlying health condition -Coping strategies -Effect on activity	*"I must say that I told nobody. I closed down"* *"XXX is always saying I could do anything, even though I was an old man. I could beat anyone. And then you get that letter come in, and you think.. and it does drag you down. And so joining different things, it takes a bit of moving on"*
Changing times	Science and technology	-Internet -Telephone signal coverage -Wireless connectivity	*"They basically they look at the index of what the regard as people require to live* (referring to measuring poverty)*, and that now includes people mobile phones, it now includes the internet, these are standard, whereas we wouldn't have dreamt of that 20 years ago"*
	Society and culture		*"What you're saying is there are far more pansies in the world these days than there used to be"*
	Health system	-NHS Systems -Health advice	*"You've got no convalescent homes as was"*
Differences and inequalities		-Different personalities -Generational differences -Geographical differences and inequality -Rural urban differences	*"I'm a country boy so you think that was a problem in the rural population, but probably I see and know more people because I know everyone around me. Whereas if you live in a street in town you don't make that same social contact, do you?"*

(continued)

Table 4 (*continued*)

Overarching themes	Sub-themes	Codes	Quotes
			"I know technology is always improving but connectivity is important, and you've got to remember where we are in this country, I mean I can't even get mobile phone signal where I was" *“For the younger generation, it's always a competition. . .to do your 10,000 steps or whatever it is"*
The NHS, people and systems		- Whose responsibility is it to follow-up patients postoperatively in the community? - Saving time for doctors - Burden or workload of the NHS - Relieving pressure on the NHS	*"As I understand, with the NHS, that basically you're good at what you do, and you get the operation done, and it's the bit between actually having the op, having a bed in the hospital, and then going home.."* *"If you have, or you need to have medical care afterwards and you're told to do things and you don't then you're putting the burden back on the NHS aren't you?"*

Table 5 Possible roles for accelerometry during the peri-operative period.

Phase	Time	Task	Rationale
Pre-operative	When scheduled for surgery	Assess baseline activity	Accelerometery derivatives correlate with CPET data. Perhaps avoid CPET. Potential for advising on surgical risk and stratifying care
		Assess baseline activity	Context for interpretation of later assessments
	Between scheduling and surgery	Monitoring progress of pre-habilitation	Possibly intervene to improve adherence
		As a therapeutic component of pre-habilitation	Provide feedback to motivate patient
Postoperative	Immediate	Track mobilisation	Facilitate interventions to enhance patient progress if they are falling off track
		Remote monitoring	Patient safety
		Provide feedback to motivate patient	Enhance effectiveness of ERAS programme
	Late	Remote monitoring	Patient safety
		Confirm return to baseline	Facilitate interventions to enhance patient progress if they are falling off track
All phases	All times	Research	Evaluate interventions and devices

CPET, cardiopulmonary exercise testing; ERAS, enhanced recovery after surgery.

expected. In either case the experimental objective would be to improve patient outcomes. Our library of raw acceleromtery files, questionnaire results and baseline characteristics will be analysed further to explore potential activity metrics.

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Supporting Information

Additional supporting information may be found online via the journal website.

Appendix S1. Survey questionnaires.