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ORIGINAL ARTICLE

Objectively measured activity is not associated with average pain intensity 1 week after surgery: A cross-sectional study

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Abstract

Background: Measures of physical activity and pain-related patient-reported outcomes are important components of patient recovery after surgery. However, little is known about their association in the early post-operative period. This study aims to increase this knowledge. Our primary objective was to determine the association between *average pain intensity* and activity (in *steps*) 1 week after surgery. Secondary objectives were the association of activity with other patient-reported outcomes, age, sex, comorbidities and body mass index.

Methods: Data were obtained from the PROMPT sub-project of IMI-PainCare. Patients after breast and endometriosis-related surgery, sternotomy and total knee arthroplasty completed pain-related outcomes questionnaires and wore an ActiGraph activity-tracking device. We correlated steps with average pain intensity on post-operative days 6 and 7. Secondary analyses were done using correlations and *t*-tests.

Results: In 284 cases, there was no statistically significant correlation between steps and average pain intensity. In addition, none of the 28 secondary analyses showed a statistically significant result.

Conclusions: Pain-related patient-reported outcome measures and physical activity are separate entities. Both should be measured after surgery to assess patient recovery and to identify treatment deficiencies.

Significance Statement: Measuring recovery is a multi-dimensional challenge. After surgery, clinicians need to be aware that neither pain intensity nor activity levels tell the whole story. Each can hint to problems and treatment requirements.

1 | INTRODUCTION

We know that pain intensity decreases (Vasilopoulos et al., 2021) and activity levels increase on average in the days after surgery (Paxton et al., 2015; Thijs et al., 2019). We also know that it can take weeks for activity levels to recover (Huang et al., 2022; Paxton et al., 2015), but there are few data on the association between pain and physical activity in the early phase after surgery (Luna et al., 2019; Sharpe et al., 2019). During this phase, rest may be a physiological and reasonable response to trauma and pain. On the other hand, data suggest an association between reduced post-operative activity and increased complications (Rivas et al., 2022). As a result, patients are often advised to get out of bed soon after surgery to improve post-operative outcomes (Paxton et al., 2015), for example, in "enhanced recovery after surgery" programmes (Haro et al., 2021; Kehlet, 2020). However, this goal is not always achieved due to fatigue and pain (Huang et al., 2022). Therefore, the aim of this study was to increase the knowledge about physical activity and pain intensity in the early post-operative period and to identify patients at risk of low activity and high pain.

Objective activity measurement using devices is more accurate and reliable than patient self-reported activity (Kuenze et al., 2019; Kwasnicki et al., 2015; Luna et al., 2019). We therefore used activity-tracking devices in patients undergoing four types of surgery: breast surgery, endometriosis surgery, sternotomy (coronary artery bypass graft or valve repair/replacement) and total knee arthroplasty (TKA). For the first three types of surgery, there was little objectively measured activity data in the literature for the first few days after surgery. For TKA, the correlation between activity and pain seems to be weak at best (Luna et al., 2019).

Our primary objective was to determine the association between *average pain intensity* and activity (in *steps*) 1 week after surgery. Secondary objectives were the association of activity with other patient-reported outcomes, age, sex, comorbidities and body mass index.

2 | METHODS

This was a sub-study of the "Providing Standardized Consented PROMs (Patient Reported Outcome Measures) for Improving Pain Treatment (PROMPT)" project (ClinicalTrials.gov Identifier: NCT03834922) (Vollert et al., 2024). PROMPT is part of the IMI-PainCare project funded by the European Commission's Innovative Medicine Initiative 2 (Grant Agreement 777500). Ethical approval was obtained from all participating hospitals (Jena University Hospital: approval number 2019-1298-Bef). All patients included in the study gave written informed consent. Patients received no compensation for their participation. We followed the STROBE guidelines (von Elm et al., 2007).

2.1 | Study population

We collected clinical data, patient-reported outcome questionnaires and activity in Bern (Switzerland), Helsinki (Finland), Homburg and Jena (both Germany). Patient recruitment was done by study physicians or study nurses at the study sites. Patients were eligible if they were 18 years or older and underwent one of the following surgeries: breast surgery, endometriosis-related surgery, sternotomy (coronary artery bypass graft and valve repair/replacement, no cancer-related surgeries) or TKA. Patients were excluded if they were cognitively impaired, unwilling to complete the follow-up questionnaires, unwilling to wear the activity trackers or if the questionnaires were not available in a language that the patients were fluent in.

2.2 | Data collection

Data were collected using different tools described below. Clinical data and patient-reported outcomes were inputted into webmasks and stored on Jena University Hospital servers. Detailed information can be found in Vollert et al. (2024) and Weinmann et al. (2023).

2.2.1 | Clinical data

The surveyors extracted the patients' clinical data from their hospital records. This included demographics, patient characteristics, diagnoses, types of surgery and medications and treatments during the peri-operative period. Data were captured using the OpenClinica software (OpenClinica LLC, Version 3.15).

2.2.2 | Patient-Reported Outcome Questionnaires

Patients completed several sets of questionnaires before surgery and on the seventh post-operative day. These included the Brief Pain Inventory short form (BPI; Cleeland & Ryan, 1994), parts of the International Pain Outcomes Questionnaire (IPO; Rothaug et al., 2013), and questions specific to their individual surgeries. Patients either completed these questionnaires online using LimeSurvey forms (LimeSurvey GmbH, Version 3.25) or were telephoned by a surveyor, who interviewed the patient and completed the relevant LimeSurvey forms.

2.2.3 | Activity data

On the first post-operative day, the surveyor placed an ActiGraph wGT3X accelerometer device on the wrist of the patient's non-dominant hand (Lee & Tse, 2019; van der Meij et al., 2017) (see Figure 1). Patients were instructed to wear the device at all times until at least the end of post-operative day 7. They returned their device to the surveyor in an envelope, which was given to them during their hospital stay. The surveyor then read out the raw data from the device. ActiLife software (ActiGraph LLC, Version 6.13.4) was used to prepare the device, read the data and score the raw activity data into *steps per minute*.

"Steps per minute" is a measure of volume. It represents the mean number of steps taken per minute during one day of activity measurement. "Steps per day" can be calculated by multiplying "steps per minute" by 1440 (60 min × 24 h).

FIGURE 1 ActiGraph wGT3X on a wrist.

2.3 | Analysed variables

Table 1 provides details of the variables analysed in this study. None of the patient-reported outcomes is a combination of other variables or multiple measurements per day.

For activity analysis, we included days when the devices were worn for at least 20 h. We used the scored *steps per minute* because these ignore non-wear time. The patient-reported outcome questions answered on post-operative day 7 covered the last 24 h and therefore extended to post-operative day 6. Therefore, we analysed the mean of *steps per minute* on post-operative days 6 and 7.

2.4 | Statistical methods

The nature of the four surgeries in the study and the heterogeneity of their patient characteristics (see Table 2) led us to analyse the surgeries individually rather than pooling them. Statistical analyses were done with R (R Foundation for Statistical Computing, Version 4.2.1) (R-Core-Team, 2021). For all tests, a *p*-value of 0.05 or less was considered statistically significant.

2.4.1 | Descriptive statistics

We present descriptive analyses of interval-scaled variables with minimum (Min), maximum (Max), mean, standard deviation (SD) and the number of missings (NA). Descriptive statistics of nominal variables (yes vs. no) show absolute and relative frequencies.

2.4.2 | Correlations and group comparisons

We report the correlation between *steps per minute* and *average pain* intensity as Pearson's *r* with 95% confidence interval (CI) for each surgery. The same approach was used for *steps per minute* and the interval-scaled secondary variables (interval-scaled variables from Table 1 besides average pain *intensity* and steps per minute). For nominal-scaled secondary analyses, we report two-sample *t*-tests with 95% CI and *steps per minute* as the dependent variable (dichotomous variables from Table 1).

2.4.3 | Linear regression model

A simple two-variable correlation may ignore the influence of known predictors of pain such as age, sex or pre-existing persistent pain (Gerbershagen et al., 2014).

TABLE 1 Analysed variables. All patient-reported outcomes were assessed on post-operative day 7.

Domain	Variable	Description
Patient characteristics	Age	Age in years
	Sex	Male vs. female
	Pre-existing persistent pain	Question: Did you have a persistent painful condition for 3 months or more before coming into hospital for this surgery?; yes vs. no
	Body mass index	Calculated as height/weight^2
	Comorbidities	Yes vs. no
Activity	Steps per minute	Mean of steps per minute on post-operative days 6 and 7
Patient-reported outcomes	Average pain intensity	Question: How intense was your pain on average during the last 24 h?; numeric rating scale from 0 (no pain) to 10 (worst pain imaginable)
	Worst pain intensity	Question: How intense was your worst pain experienced during the last 24 h?; numeric rating scale from 0 (no pain) to 10 (worst pain imaginable)
	Pain intensity at rest	Question: How intense is your pain currently at rest while lying in bed?; numeric rating scale from 0 (no pain) to 10 (worst pain imaginable)
	Surgery-specific pain intensity during activity	Question breast surgery: How intense is your pain currently while lifting your extended arm sideways on the operated side? Question endometriosis surgery: How intense is your pain currently while changing from the lying position to sitting upright? Question sternotomy: How intense is your pain currently while taking a deep breath? Question TKA: How intense is your pain currently while bending your operated knee? Numeric rating scale from 0 (no pain) to 10 (worst pain imaginable)
	Pain relief	Question: Since your surgery, how much pain relief have you received?; 11-point scale from 0% to 100%
	Pain interference with activities in bed	Question: How much, in the last 24 h, pain interfered with or prevented you from doing activities in bed such as turning, sitting up, changing position?; numeric rating scale from 0 (does not interfere) to 10 (completely interferes)
	Participation in pain treatment	Question: Were you allowed to participate in decisions about your pain treatment as much as you wanted to?; numeric rating scale from 0 (not at all) to 10 (very much so)
	Desire for more pain treatment	Question: Would you have liked MORE pain treatment than you received?; yes vs. no

Furthermore, these variables and body mass index might also influence activity (Cheatham et al., 2018; Quinlan et al., 2021). Therefore, we calculated linear regression models for each surgery. In these models, patient characteristics and *average pain intensity* served as independent variables while *steps per minute* was the dependent variable. We report the R^2 and p-values of the models as well as the coefficients and their p-values.

2.4.4 | Activity trajectories

The literature suggests that activity trajectories during the first post-operative days may have an influence on pain (Luna et al., 2017, 2019; Sharpe et al., 2019). We calculated the trajectories of *steps per minute* for each patient with linear mixed effect models similar to Gorzelitz et al. (2019), that is, *steps per minute* were modelled as random effects. We then calculated linear regression models with *average pain intensity* as the dependent variable. As predictors, we used the same variables as before plus the trajectory slopes to find out if these slopes were a predictor of *average pain intensity*.

3 | RESULTS

Data were collected from October 2019 to December 2021. We analysed data from 284 patients for the correlation between *steps per minute* and *average pain intensity*. For secondary analyses of patient characteristics and activity, we also used activity data from patients who did not respond to the questionnaires on post-operative day 7. Figure 2 shows the flow chart of patient inclusion and exclusion.

3.1 | Descriptives

3.1.1 | Patent characteristics

Table 2 presents descriptive statistics of patient characteristics. Information on the relative frequencies of specific

TABLE 2 Characteristics of patients included for primary and secondary analyses.

Label	Variable	Surgery: Breast surgery	Surgery: Endometriosis	Surgery: Sternotomy	Surgery: TKA	Total
Age	Min/Max	27.0/80.0	18.0/75.0	19.0/82.0	41.0/85.0	18.0/85.0
	Mean (SD)	54.4 (12.0)	32.5 (9.4)	61.8 (10.9)	65.4 (10.3)	54.9 (15.9)
	N (NA)	73 (0)	64 (0)	127 (0)	55 (0)	319 (0)
Body mass index	Min/Max	17.8/42.2	15.6/37.2	16.0/47.4	20.7/54.3	15.6/54.3
	Mean (SD)	25.8 (5.5)	24.8 (4.9)	28.2 (5.4)	30.6 (6.4)	27.4 (5.8)
	N (NA)	73 (0)	64 (0)	127 (0)	55 (0)	319 (0)
Sex	Male	0 (0%)	0 (0%)	100 (78.7%)	23 (41.8%)	123 (38.6%)
	Female	73 (100.0%)	64 (100.0%)	27 (21.3%)	32 (58.2%)	196 (61.4%)
Comorbidities	No	6 (8.2%)	31 (48.4%)	11 (8.7%)	7 (12.7%)	55 (17.2%)
	Yes	67 (91.8%)	33 (51.6%)	116 (91.3%)	48 (87.3%)	264 (82.8%)
Pre-existing persistent pain	No	57 (81.4%)	21 (33.9%)	100 (82.6%)	7 (12.7%)	185 (60.1%)
	Yes	13 (18.6%)	41 (66.1%)	21 (17.4%)	48 (87.3%)	123 (39.9%)
	NA	3	2	6	0	11

Abbreviations: IQR, inter-quartile range; *N*, number of patients; NA, missing; SD, standard deviation; TKA, total knee arthroplasty.

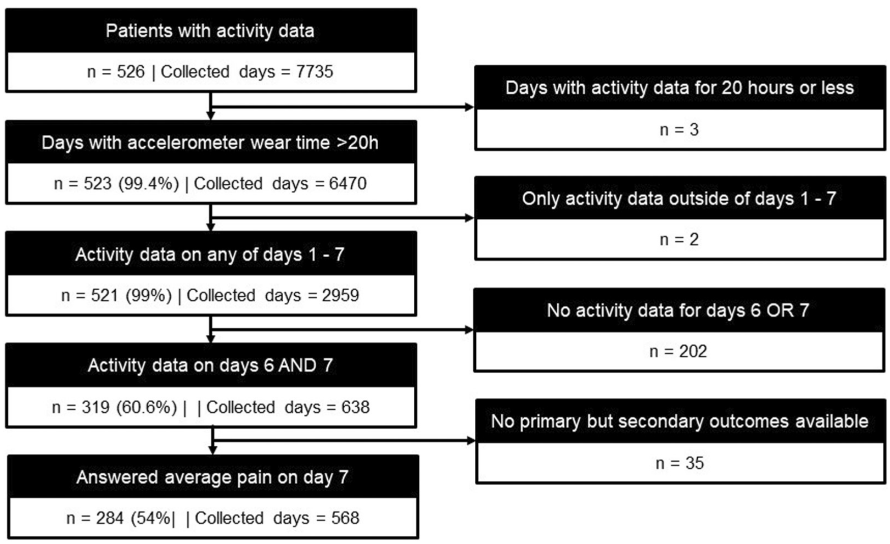

FIGURE 2 Flow chart of included patient data.

comorbidities can be found in Table S1. Comparing included and excluded cases, patient characteristics were not statistically different in breast surgery, endometriosis surgery, sternotomy and three out of four characteristics in TKA. Included TKA patients had a significantly higher body mass index (30.6 compared to 26.2, $p = 0.04$), see Table S2 for details.

3.1.2 | Peri-operative and post-operative treatment

Table 3 presents data on general anaesthesia (intra-operative), regional anaesthesia (intra-operative, post-operative day 1, POD3), opioid medication (intra-operative, POD1, POD3, POD7) and the application of physiotherapy (POD1, POD3, POD7).

3.1.3 | Patient-reported outcomes

Descriptive statistics for the pain-related patient-reported outcome measures are presented in Table 4.

3.1.4 | Activity

The average *steps per minute* for each day of the first post-operative week are illustrated in Figure 3 (numbers in Table S6). Details for *steps per minute* on post-operative

TABLE 3 Frequencies of peri-opreative and post-operative treatment and opioid medication for each type of surgery.

Label	Variable	Surgery: Breast surgery	Endometriosis	Sternotomy	TKA	Total
General anaesthesia	No	0 (0%)	1 (1.6%)	0 (0%)	4 (7.3%)	5 (1.6%)
	Yes	73 (100.0%)	63 (98.4%)	127 (100.0%)	51 (92.7%)	314 (98.4%)
Regional anaesthesia intra-op	No	68 (93.2%)	27 (42.2%)	117 (92.1%)	10 (18.2%)	222 (69.6%)
	Yes	5 (6.8%)	37 (57.8%)	10 (7.9%)	45 (81.8%)	97 (30.4%)
Regional anaesthesia POD1	No	73 (100.0%)	55 (85.9%)	127 (100.0%)	29 (52.7%)	284 (89.0%)
	Yes	0 (0%)	9 (14.1%)	0 (0%)	26 (47.3%)	35 (11.0%)
Regional anaesthesia POD3	No	57 (100.0%)	32 (86.5%)	127 (100.0%)	43 (81.1%)	259 (94.5%)
	Yes	0 (0%)	5 (13.5%)	0 (0%)	10 (18.9%)	15 (5.5%)
	NA	16	27	0	2	45
Opiioids intra-op	No	0 (0%)	0 (0%)	0 (0%)	3 (5.5%)	3 (0.9%)
	Yes	73 (100.0%)	64 (100.0%)	127 (100.0%)	52 (94.5%)	316 (99.1%)
Opioids POD1	No	73 (100.0%)	54 (84.4%)	23 (18.1%)	0 (0%)	150 (47.0%)
	Yes	0 (0%)	10 (15.6%)	104 (81.9%)	55 (100.0%)	169 (53.0%)
Opioids POD3	No	55 (98.2%)	36 (100.0%)	81 (63.8%)	4 (7.5%)	176 (64.7%)
	Yes	1 (1.8%)	0 (0%)	46 (36.2%)	49 (92.5%)	96 (35.3%)
	NA	17	28	0	2	47
Opioids POD7	No	62 (98.4%)	54 (98.2%)	102 (90.3%)	23 (46.0%)	241 (85.8%)
	Yes	1 (1.6%)	1 (1.8%)	11 (9.7%)	27 (54.0%)	40 (14.2%)
	NA	10	9	14	5	38
Physiotherapy POD1	No	56 (80.0%)	59 (96.7%)	54 (58.7%)	15 (32.6%)	184 (68.4%)
	Yes	14 (20.0%)	2 (3.3%)	38 (41.3%)	31 (67.4%)	85 (31.6%)
	NA	3	3	35	9	50
Physiotherapy POD3	No	44 (77.2%)	45 (86.5%)	44 (35.8%)	9 (17.6%)	142 (50.2%)
	Yes	13 (22.8%)	7 (13.5%)	79 (64.2%)	42 (82.4%)	141 (49.8%)
	NA	16	12	4	4	36
Physiotherapy POD7	No	55 (87.3%)	58 (100.0%)	63 (54.8%)	3 (6.0%)	179 (62.6%)
	Yes	8 (12.7%)	0 (0%)	52 (45.2%)	47 (94.0%)	107 (37.4%)
	NA	10	6	12	5	33

days 6 and 7 are shown in Table 5. 317 (99%) of the included patients wore the tracker for a sum of 48 h on days 6 and 7. The remaining two patients did not wear it for 68 and 210 min, respectively.

3.2 | Correlations/group differences

3.2.1 | Steps and patient-reported outcomes

Average pain intensity and *steps per minute* on post-operative days 6 and 7 had no statistically significant correlation for any surgery (see Figure 4 for an illustration and Table S3 for detailed correlation results).

We also correlated *steps per minute* with *worst pain intensity*, *pain intensity at rest*, *surgery-specific pain*, *pain relief*, *pain interference with activities in bed* and *participation in pain treatment decisions*. Of these 24 secondary correlations (6 interval-scaled secondary variables × 4 surgeries), none were statistically significant (see Table S4). There was also no statistically significant difference in activity between patients who desired more pain treatment and those who did not (see Table S5).

3.2.2 | Steps and patient characteristics

Steps per minute and *age* were not statistically significantly correlated for breast surgery. For endometriosis surgery ($r = 0.39$, $p < 0.01$), sternotomy ($r = -0.22$, $p = 0.01$), and TKA ($r = -0.3$, $p = 0.03$), the correlation was statistically significant. See Figure 5 for an illustration.

TABLE 4 Descriptive statistics of pain-related patient-reported outcomes, answered by patients once on post-operative day 7 (questions sources: Brief Pain Inventory and PAIN OUT).

		Surgery				
Label	Variable	Breast surgery	Endometriosis	Sternotomy	TKA	Total
Average pain intensity	Min/Max	0/5.0	0/8.0	0/8.0	0/8.0	0/8.0
	Mean (SD)	1.3 (1.1)	1.9 (1.7)	2.4 (2.0)	3.8 (2.1)	2.3 (1.9)
	N (NA)	63 (10)	57 (7)	115 (12)	49 (6)	284 (35)
Worst pain intensity	Min/Max	0/5.0	0/8.0	0/10.0	0/10.0	0/10.0
	Mean (SD)	1.9 (1.6)	2.9 (2.1)	3.6 (2.3)	5.6 (2.5)	3.5 (2.5)
	N (NA)	63 (10)	58 (6)	115 (12)	49 (6)	285 (34)
Pain intensity at rest	Min/Max	0/4.0	0/8.0	0/8.0	0/7.0	0/8.0
	Mean (SD)	0.7 (1.0)	1.3 (1.5)	1.7 (1.7)	2.8 (1.7)	1.6 (1.7)
	N (NA)	63 (10)	58 (6)	115 (12)	50 (5)	286 (33)
Surgery-specific pain intensity during activity	Min/Max	0/5.0	0/8.0	0/8.0	0/10.0	
	Mean (SD)	1.7 (1.6)	1.9 (1.6)	2.7 (2.1)	5.0 (2.1)	
	N (NA)	61 (12)	57 (7)	115 (12)	49 (6)	
Pain relief	Min/Max	0/100.0	20.0/100.0	0/100.0	20.0/90.0	0/100.0
	Mean (SD)	77.4 (24.1)	72.4 (18.2)	71.4 (22.6)	63.6 (20.3)	71.6 (22.1)
	N (NA)	62 (11)	54 (10)	110 (17)	47 (8)	273 (46)
Pain interference with activities in bed	Min/Max	0/10.0	0/7.0	0/9.0	0/8.0	0/10.0
	Mean (SD)	2.4 (2.2)	1.8 (1.5)	3.5 (2.3)	3.3 (2.0)	2.9 (2.2)
	N (NA)	63 (10)	58 (6)	114 (13)	48 (7)	283 (36)
Participation in pain treatment	Min/Max	0/10.0	0/10.0	0/10.0	0/10.0	0/10.0
	Mean (SD)	6.0 (3.8)	6.2 (3.6)	7.2 (3.1)	7.1 (2.9)	6.7 (3.4)
	N (NA)	62 (11)	53 (11)	106 (21)	48 (7)	269 (50)
Desire for more pain treatment	0	57 (90.5%)	43 (79.6%)	101 (89.4%)	36 (73.5%)	237 (84.9%)
	1	6 (9.5%)	11 (20.4%)	12 (10.6%)	13 (26.5%)	42 (15.1%)
	NA	10	10	14	6	40

Abbreviations: IQR, inter-quartile range; *N*, number of patients; NA, missing; SD, standard deviation; TKA, total knee arthroplasty.

Steps per minute and *body mass index* were statistically significantly correlated only for breast surgery ($r = -0.32$, $p < 0.01$). There was no correlation for the other three surgeries.

T-tests showed statistically significant differences between the sexes after sternotomy (male mean steps per minute = 3.38, female = 2.54, $p = 0.03$) but not for TKA. This was not tested for breast and endometriosis surgery as these patients were all female.

A difference between patients with and without pre-existing persistent pain was only found for breast surgery (group “no” mean steps per minute = 6.57, “yes” = 4.22, $p < 0.01$). There was no difference for the other three surgeries.

We found no difference in activity between patients with and without comorbidities for any surgery.

3.3 | Linear regression model

Details of the regression models for each surgery are shown in Table 6. Only the breast surgery and sternotomy models were statistically significant and are discussed further. In the breast surgery model, body mass index was the only independent variable that had a statistically significant effect on *steps per minute*. Patients with a higher body mass index moved less in this model. In the sternotomy model, older age had a statistically significant activity-decreasing effect. None of the other independent variables showed statistical significance in this model.

3.4 | Activity trajectories

Across all surgeries, 17.2% of patients had decreasing activity trajectory slopes (see Table S7 for slope distribution). However, these slopes were no statistically significant predictor of average pain *intensity* on post-operative day 7 in linear regression models (see Table S8). Clustering trajectories yielded no results (see Figure S1).

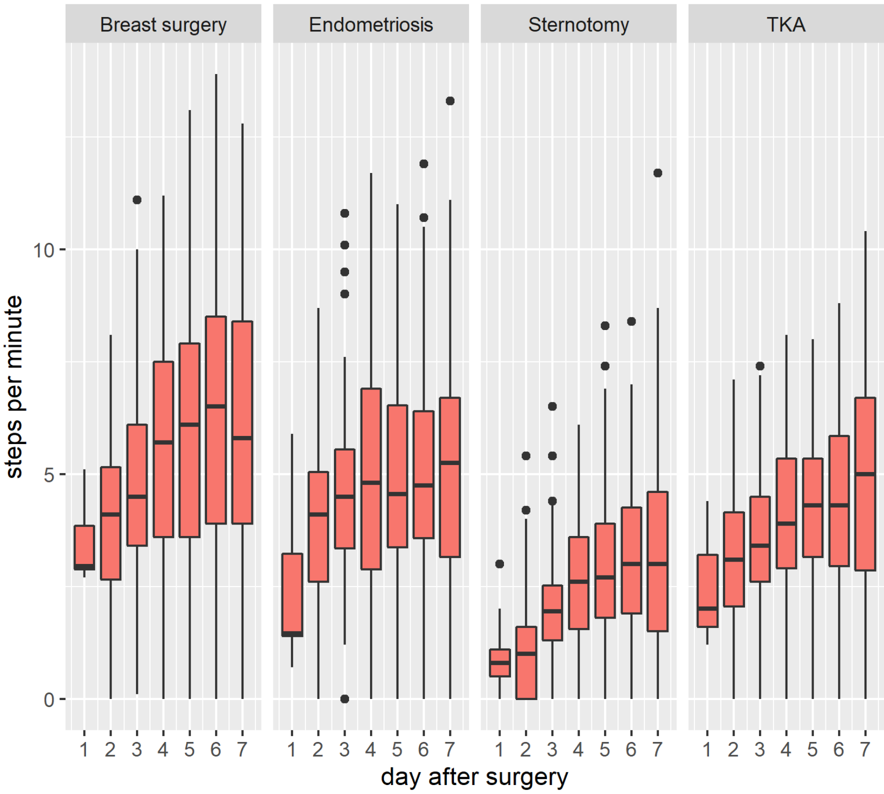

FIGURE 3 Boxplots of average steps per minute in the first 7 days after surgery. TKA, total knee arthroplasty.

TABLE 5 Descriptive statistics of steps per minute on post-operative days 6 and 7.

Label	Variable	Surgery: Breast surgery	Endometriosis	Sternotomy	TKA	Total
Steps per minute	Min/Max	0/13.2	0/12.6	0/8.6	0/9.6	0/13.2
	Mean (SD)	6.2 (3.2)	5.0 (2.9)	3.2 (2.1)	4.5 (2.3)	4.5 (2.8)
	N (NA)	73 (0)	64 (0)	127 (0)	55 (0)	319 (0)

Abbreviations: IQR, inter-quartile range; *N*, number of patients; NA, missing; SD, standard deviation; TKA, total knee arthroplasty.

4 | DISCUSSION

We analysed 284 patients after four types of surgery for the association between physical activity (in *steps per minute*) and *average pain intensity* on post-operative days 6 and 7. No statistical significant correlation was found. Adjustment for variables known to predict pain or activity did not change the results. In up to 319 patients, none of 28 secondary analyses showed a statistically significant result for the association between activity and patient characteristics or other patient-reported outcome measures.

4.1 | Steps as a measure of activity

The choice of steps (per minute or per day—they can be easily transformed into each other) as a measure of activity is debatable. Other studies use sedentary analyses or calculate mild, moderate and heavy activity from raw accelerometer data. This multi-dimensionality may be required for specific research questions but also poses a problem for study result comparisons.

We chose steps for three main reasons. First, steps do not use cut-offs or other classification methods that decrease the information collected as raw data. For example, the definition of “moderate activity” ultimately is a question of definition. Second, almost all of the literature we present in this article used steps as a measure of activity. The third reason is a little softer: Steps is a measure that is relatively easy to interpret by author and reader. This is probably the reason why a lot of literature uses it, too.

4.2 | Data collection

We could analyse almost all patients who started wearing an activity device after breast surgery, endometriosis surgery and TKA. However, a large number of sternotomy

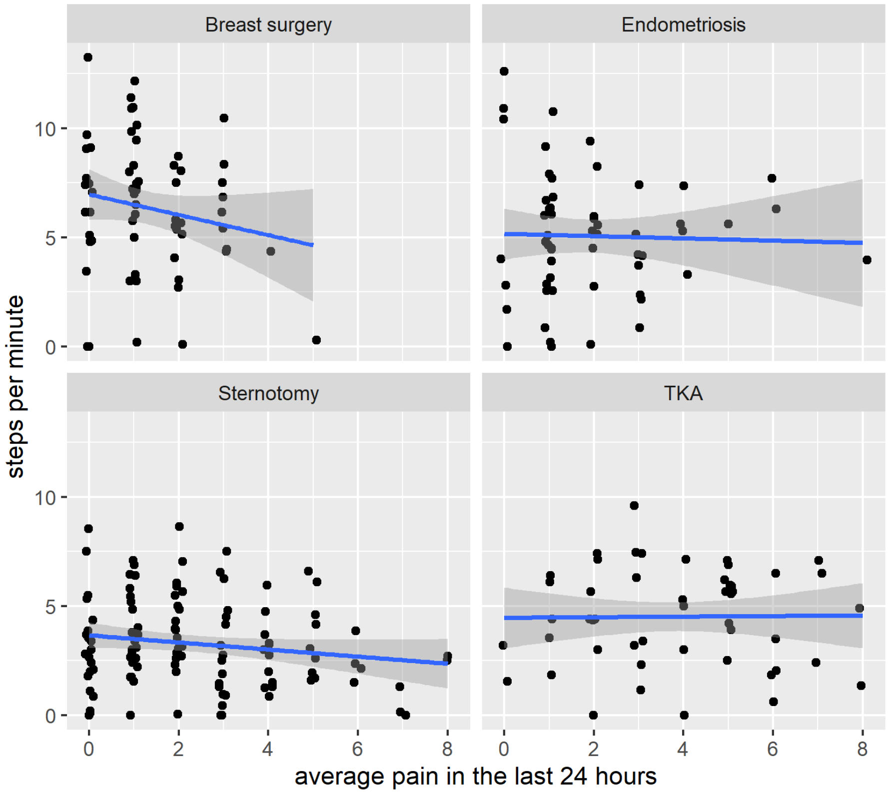

FIGURE 4 Steps per minute as a function of average pain intensity on post-operative days 6 and 7. TKA, total knee arthroplasty.

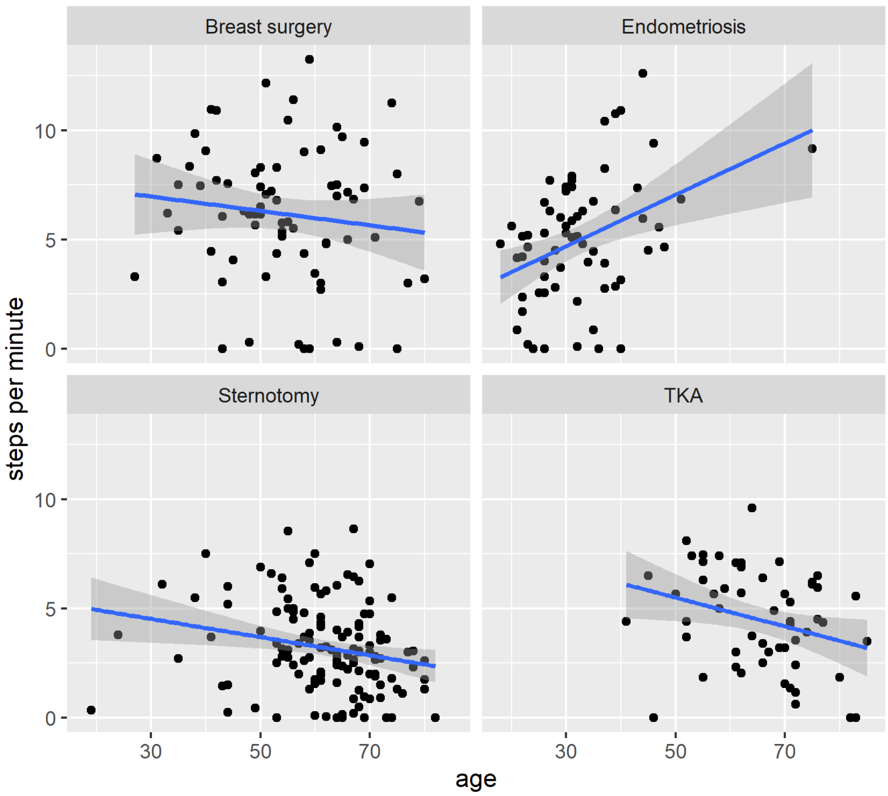

FIGURE 5 Plot of age and steps per minute with regression line. TKA, total knee arthroplasty.

cases were lost during the first days after surgery. Higher age thus did not seem to be the problem, here, as TKA patients were of similar age. Data collectors reported that sternotomy patients often felt overwhelmed by their clinical situation. This resulted in patients not completing their follow-up questionnaires or taking off their activity devices because they did not want yet another device on their bodies. Nevertheless, the number of sternotomy

TABLE 6 Linear regression models for each type of surgery.

	Breast surgery	Endometriosis	Sternotomy	TKA
(Intercept)	15.48***	2.88	6.87***	11.85**
	[0.00]	[0.25]	[0.00]	[0.00]
Age	−0.06	0.12**	−0.06**	−0.07*
	[0.10]	[0.01]	[0.00]	[0.05]
Body mass index	−0.16*	−0.05	0.02	−0.09
	[0.02]	[0.59]	[0.62]	[0.09]
Pre-existing persistent pain	−1.41	−0.76	0.13	1.29
	[0.15]	[0.35]	[0.82]	[0.25]
Comorbidities: yes	−0.73	−0.20	−0.16	−1.21
	[0.62]	[0.80]	[0.82]	[0.32]
Average pain	−0.45	0.03	−0.13	0.04
	[0.17]	[0.89]	[0.19]	[0.82]
Sex: female			−0.85	−0.48
			[0.06]	[0.52]
n	60	56	110	49
R^2	0.23	0.17	0.14	0.19
p	0.01	0.08	0.02	0.17

Note: Steps per minute was the dependent variable. *p*-values are in brackets.
Abbreviation: TKA, total knee arthroplasty.
***$p < 0.001$; **$p < 0.01$; *$p < 0.05$.

cases remained the highest in the analysis and there was no difference between characteristics of included and excluded sternotomy patients.

4.3 | Activity after surgery

On average, *steps per minute* increased each day after surgery. Breast and endometriosis surgery patients recovered faster than patients after sternotomy or TKA. Reduced activity recovery in the first weeks after TKA has been reported before (Paxton et al., 2015). Hayashi wrote that TKA patients had an average maximum daily step count of 2181 between post-operative days 3 and 10 (Hayashi et al., 2018). Husby reported a similar number on day 6 (Husby et al., 2023). Both numbers are lower than our results on days 6 and 7. The improvement in activity from day 1 to 7 in our TKA group was 80.6%, whereas in Luna's article (Luna et al., 2019) it was only 16% (171–204 counts). Luna also reported that activity levels in TKA patients did not fully recover in the first 3 weeks after surgery.

There is limited literature on short-term post-operative activity for surgeries other than TKA, with Thijs reporting that the median number of steps in the first week after bypass surgery was 3715 (conventional bypass) and 1001 (robot-assisted minimally invasive bypass) (Thijs et al., 2019). Huang found that activity did not fully recover within the first 7 days after discharge following thoracoscopic lobectomy and an enhanced recovery after surgery programme (Huang et al., 2022). The main reasons were fatigue in 43% and pain in 33% of patients. Women after caesarean section increased their activity over time according to a logarithmic function (Sharpe et al., 2019).

4.4 | Association of activity, pain and patient characteristics

We found no association between pain-related outcomes and activity 1 week after surgery. This is also true for each surgery and its surgery-specific pain intensity during well-defined function, which may have yielded different results due to the variation in surgical models. For TKA, our results are similar to Krenk et al. (2013) and Luna et al. (2017, 2019), where no or very weak associations were found. On the other hand, higher pain scores were associated with a lower number of steps in TKA patients in Husby et al. (2023).

Older age had a decreasing effect on activity in the linear model for sternotomy. Higher body mass index was associated with decreased activity only after breast surgery. Other patient characteristics were not associated with activity. Luna reported that body mass index for TKA and post-operative pain for TKA were only weakly associated with reduced physical activity (Luna et al., 2019). None of their suggested factors was associated with poor recovery. In a study enrolling patients with endometrial cancer, neither body mass index nor age or type of surgery was associated with activity (Gorzelitz et al., 2019). The lack of association between pre-operative persistent pain and post-operative physical activity may be partly explained by the fact that the surgery reduced the cause of the persistent pain in some patients.

After breast surgery (mean pain intensity: 1.3) and endometriosis surgery (1.9), the *average pain intensity* on day 7 is already relatively low and does not show a wide distribution. This may explain why there was no correlation with activity. However, the results also hold for the worst pain intensity, where the distribution is not so skewed towards zero pain intensity.

4.5 | Activity may be a separate entity

In conclusion, measuring activity with an Actigraph is not a substitute for asking patients about their pain outcomes. On the contrary, activity and pain outcomes seem to be complementary entities. This raises the question of whether measuring one is superior to the other.

Pain is a complex and subjective phenomenon. Patient-reported pain pain-related outcomes might be influenced not only by the type of surgery and treatment, but also by genetics, socio-economic background, culture, ethnicity or other factors (Dorner et al., 2011; Narayan, 2010; Orhan et al., 2018; Packiasabapathy et al., 2018). In addition, the survey process may have an impact on patient responses. However, we also know that asking patients about their pain and involving them in the treatment process are major factors for patient satisfaction (Komann et al., 2021).

Objectively measured activity may have advantages. It allows clinicians to identify poor recovery and improve shared decision making. However, it could be influenced by the same factors as pain and local treatment policies if these encourage patients to move or provide different intensities of physiotherapy (Rivas et al., 2022). On the other hand, physical activity can be monitored with devices that are widely available, reliable and relatively inexpensive.

This study had some shortcomings. First, our study did not collect pre-operative activity data. Pre-operative activity levels may be a predictor for post-operative activity and might have helped to explain some of the variance in the patient sample. Second, our sample size may have been too small. Some of the analyses showed a trend towards not-so-small effects. However, compared with similar studies, we had reasonable case numbers and the results are the same for our largest group, sternotomy. Third, we did 40 statistical tests, which would normally require alpha-error correction. In our study, however, only a few results were statistically significant, which means that the probability of alpha-errors is low. Finally, activity is influenced by many factors. It is possible that there are confounders for low activity that we were not able to analyse.

In our study, there was no association between subjective patient-reported outcomes and objective activity 1 week after surgery. We suggest to assess both in daily routine. In this way, clinicians can identify patients with poor recovery on any measure and get them back to normal as soon as possible. Future studies should investigate whether physical activity is associated with long-term outcomes (e.g., chronic post-surgical pain), whether it can be promoted by specific interventions and how to determine the optimal level of physical activity after surgery.

AUTHOR CONTRIBUTIONS

Conception and design: MK, JD and WM; *Acquisition of data*: MK, JD, CW, EK, US, TV and WM; *Analysis and interpretation of data*: all authors; *Drafting the article*: MK, JD, CW and WM; *Revising the article*: all authors; Final approval: all authors.

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CONFLICT OF INTEREST STATEMENT

MK, JD, PB, CW and US declare no conflict of interest. EK has received fees for advisory board or lecture activities from Oriona Pharma, Pfizer and GSK. TV received consultation fees and payment for lectures from CSL Behring, Pajunk and BBraun. His institution has received research funding from Sedana medical and BBraun. EPZ received financial support from Grunenthal for research activities and advisory and lecture fees from Grünenthal, Novartis and Medtronic. In addition, she receives scientific support from the German Research Foundation (DFG), the Federal Ministry of Education and Research (BMBF), the Federal Joint Committee (G-BA) and the Innovative Medicines Initiative 2 Joint Undertaking under grant agreement No 777500. This Joint Undertaking receives

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