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Device-Measured Physical Activity in 3506 Individuals with Knee or Hip Arthroplasty

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ABSTRACT

SMALL, S. R., S. KHALID, A. J. PRICE, and A. DOHERTY. Device-Measured Physical Activity in 3506 Individuals with Knee or Hip Arthroplasty. *Med. Sci. Sports Exerc.*, Vol. 56, No. 5, pp. 805–812, 2024. **Purpose:** Hip and knee arthroplasty aims to reduce joint pain and increase functional mobility in patients with osteoarthritis; however, the degree to which arthroplasty is associated with higher physical activity is unclear. The current study sought to assess the association of hip and knee arthroplasty with objectively measured physical activity. **Methods:** This cross-sectional study analyzed wrist-worn accelerometer data collected in 2013–2016 from UK Biobank participants (aged 43–78 yr). Multivariable linear regression was performed to assess step count, cadence, overall acceleration, and activity behaviors between nonarthritic controls, end-stage arthritic, and postoperative cohorts, controlling for demographic and behavioral confounders. From a cohort of 94,707 participants with valid accelerometer wear time and complete self-reported data, electronic health records were used to identify 3506 participants having undergone primary or revision hip or knee arthroplasty and 68,389 nonarthritic controls. **Results:** End-stage hip or knee arthritis was associated with taking 1129 fewer steps per day (95% confidence interval (CI), 811–1447; $P < 0.001$) and having 5.8 fewer minutes per day (95% CI, 3.0–8.7; $P < 0.001$) of moderate-to-vigorous activity compared with nonarthritic controls. Unilateral primary hip and knee arthroplasties were associated with 877 (95% CI, 284–1471; $P = 0.004$) and 893 (95% CI, 232–1554; $P = 0.008$) more steps than end-stage osteoarthritic participants, respectively. Postoperative unilateral hip arthroplasty participants demonstrated levels of moderate-to-vigorous physical activity and daily step count equivalent to nonarthritic controls. No difference in physical activity was observed between any cohorts in terms of overall acceleration, or time spent in daily light activity, sedentary behavior, or sleep. **Conclusions:** Hip and knee arthroplasties are associated with higher levels of physical activity compared with participants with end-stage arthritis. Unilateral hip arthroplasty patients, in particular, demonstrate equivalence to nonarthritic peers at more than 1 yr after surgery. **Key Words:** REPLACEMENT, DIGITAL HEALTH, ACCELEROMETRY, BIG DATA

Physical activity and mobility are key areas of focus for rehabilitation and perioperative care to improve joint function and patient quality of life after hip and knee arthroplasty as treatment for end-stage osteoarthritis. Historically, physical activity in orthopedic populations has been assessed primarily through the use of self-reported physical activity questionnaires (1). Self-reported physical activity questionnaires suffer from significant recall bias and have been preferentially replaced with wearable-measured physical activity assessment in large-scale epidemiological studies (2,3). However, recent investigations of wearable-measured physical activity in lower limb arthroplasty clinical cohorts are predominantly composed of small ($n < 100$), select, or nominally matched cohorts, leading to conflicting evidence regarding postoperative levels of physical activity after joint replacement surgery (1,4,5).

Although knee and hip arthroplasty are well-established surgical interventions (6,7), key questions around physical activity in the clinical population remain unresolved, namely: 1) What is the impact of end-stage knee or hip osteoarthritis on physical activity compared with a peer nonarthritic population? 2) Does surgical intervention lead to elevated physical activity levels after full recovery? 3) After recovery, do arthroplasty patients reach expected activity levels equivalent to their nonarthritic peers?

We therefore aimed to quantify differences in device-measured physical activity between nonarthritic controls, participants with end-stage hip or knee osteoarthritis, and participants having undergone hip or knee arthroplasty. We additionally aimed to address historical challenges of small sample size,

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Submitted for publication August 2023.
Accepted for publication November 2023.
Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's Web site (www.acsm-msse.org).

0195-9131/24/5605-0805/0
MEDICINE & SCIENCE IN SPORTS & EXERCISE®

DOI: 10.1249/MSS.0000000000003365

selection bias, and poorly controlled confounders, which hinder the generalizability of many studies in the current orthopedic literature.

METHODS

Activity measurement. Between 2013 and 2016, over 100,000 UK Biobank participants agreed to wear an Axivity AX3 accelerometer on their dominant wrist, recording at a sampling rate of 100 Hz and resolution of ±8*g* for 24 h a day for 7 d. Acceleration metrics and machine learning–derived behavioral classification were retrieved from accelerometer-derived variables from the UK Biobank dataset (2,8). The metric of overall acceleration is generated using accelerometer data processed through a previously described series of resampling, calibration, and low-pass filtering (2). A validated random forest and hidden Markov behavior model was used to allocate time use into sleep, sedentary, light activity, and moderate-to-vigorous physical activity (MVPA) classifications (8). Raw accelerometer data for each participant were additionally accessed for this study to calculate median daily step count and peak cadence using the OxWearables stepcount package (v2.1.5), a hybrid self-supervised machine learning step detection algorithm that has previously demonstrated high accuracy in free-living validation (9). For each participant, valid wear time was considered a contribution of at least 72 h of accelerometer wear, in addition to a contribution of at least 1 h of wear during each 1-h period over the 24-h clock (2). Participants with an improbable average acceleration of over 100 mg were excluded from the accelerometry cohort.

Health data linkage. The National Health Service Hospital Episode Statistics is linked with the UK Biobank, containing data from 1997 to 2021 for participants in England, 1998 to 2016 in Wales, and 1981 to 2021 in Scotland (10). Operative odes are listed in the Office of Population Censuses and Surveys Classification of Interventions and Procedures, version 4 (OPCS-4) coding classification system, whereas *International Classification of Diseases, Ninth and Tenth Revisions* (*ICD-9*) and *ICD-10* codes are used for in-hospital admission episode diagnoses. A modified Charlson Comorbidity Index, ranging from 0 to 50, was used to quantify the multimorbidity status of all participants (11,12). Charlson Comorbidity Index was calculated based on *ICD-10* data linkage for each participant within a 5-yr lookback window from the start date of the participant's accelerometer wear period.

Cohort generation. A flow diagram for study cohort generation is presented in Figure 1. OPCS-4 code definitions from the National Joint Registry (13) were used to identify participants with any documented history of primary or revision knee or hip arthroplasty. Participants who wore an accelerometer less than 12 months after their first hip or knee arthroplasty were considered still in transient early recovery and were not included in this analysis, as prior literature has demonstrated functional improvement typically plateaus between 6 months and 2 yr postoperatively (14–16). In addition, participants who received their first hip or knee arthroplasty more than 12 months into the future after accelerometer wear were also removed.

To assess physical activity associated with any combination of primary or revision knee and hip arthroplasty, two initial study groups were created. The first group consisted of end-stage osteoarthritic participants who underwent their first primary knee or hip arthroplasty less than 12 months after accelerometer wear. The second group consisted of participants with any number of hip or knee arthroplasties, having had their first primary arthroplasty at least 12 months before accelerometer wear. For

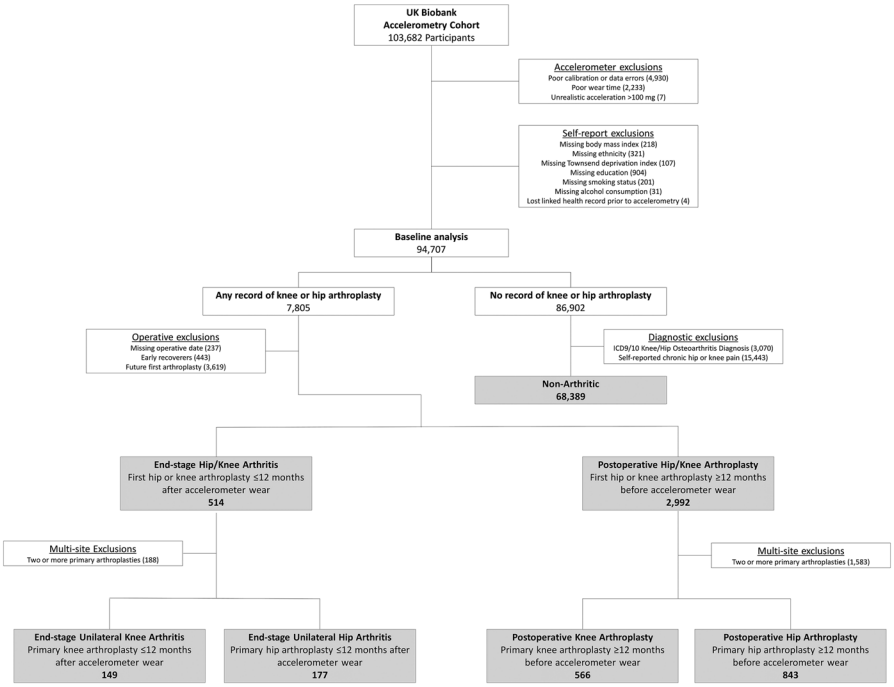

FIGURE 1—Participant flowchart. Nonarthritic and clinical participant subgroups based on operative status and timing relative to accelerometer wear date. Excluded early recoverers are considered participants who wore an accelerometer less than 12 months after their first primary hip or knee arthroplasty. Participants were also excluded if their first primary hip or knee arthroplasty was conducted more than 12 months after accelerometer wear.

a second analysis in more clearly defined cohorts, participants with only a single, unilateral primary knee or hip arthroplasty at any point in their medical records were selected from the initial cohorts. Participants who had one or more subsequent revisions of the single primary arthroplasty were also included. Once arthroplasty patients were identified, cohorts were delineated into four subgroups: end-stage unilateral knee osteoarthritis with no arthroplasty at the time of accelerometer wear, end-stage unilateral hip osteoarthritis with no arthroplasty at the time of accelerometer wear, postoperative with a single-site primary or revised knee arthroplasty at the time of accelerometer wear, and postoperative with a single-site primary or revised hip arthroplasty at the time of accelerometer wear.

A reference cohort of nonarthritic controls was selected for comparison with knee and hip arthroplasty cohorts. The nonarthritic reference cohort was defined as any UK Biobank participant with valid accelerometer wear time, no medical record of hip or knee arthroplasty up to the latest point of health record update, no hip or knee osteoarthritis diagnosis, and no self-report of chronic (3+ months) of hip pain or knee pain at any follow-up appointment or interaction with the UK Biobank. All combinations of OPCS and *ICD* codes used for cohort generation are listed in the Supplemental Digital Content (Supplemental Table 1, Standalone operative codes, http://links.lww.com/MSS/C988; Supplemental Table 2, Combination operative codes, Supplemental Digital Content, http://links.lww.com/MSS/C988).

Statistical analysis. Multivariable linear regression was performed to compare physical activity between selected clinical cohorts. Confounders for adjustment in the regression model were selected from UK Biobank variables having a significant correlation with physical activity in other epidemiological studies, including age at the time of wear, sex, ethnic background, education level, smoking status, alcohol consumption status, Townsend Deprivation Index, wear season, and Charlson Comorbidity Index (2,8,17). Because of low overall missingness within the UK Biobank, a complete-case analysis was performed; participants with missing data in any of the confounding exposure variables were removed from the analysis. Primary outcome metrics of interest were step count, peak cadence, overall acceleration, and machine learning–classified MVPA. Additional measures of machine learning classified light activity, sedentary activity, and sleep were quantified as a secondary analysis. Separate regression models for each physical activity outcome measure were generated. All statistical analyses were performed using R (v4.1.0) on the Biomedical Research Cluster at the University of Oxford Big Data Institute.

RESULTS

Baseline demographics of the UK Biobank clinical cohorts with valid accelerometer wear and self-reported demographic data are presented in Table 1. A total of 7805 participants were identified as having any record of knee or hip arthroplasty, with 3506 having their first arthroplasty at least 12 months before or within 12 months after accelerometer wear. Of these, 149 participants contributed valid accelerometer wear less than 12 months before the primary knee arthroplasty, whereas 566 participants wore the accelerometer 12 or more months after the primary knee arthroplasty. A total of 177 participants wore an accelerometer less than 12 months before a single unilateral hip arthroplasty, and 843 wore an accelerometer more than 12 months after a single-hip arthroplasty. To serve as a reference baseline, 68,389 participants were identified as having had no hip or knee arthroplasty, lower limb osteoarthritis, or chronic hip or knee pain. Consistent with the broader UK Biobank cohort, all clinical subgroups consisted of primarily White ethnicity with approximately 50% of participants coming from the least deprived quintile of the broader population of the United Kingdom.

Physical activity and mobility associated with any hip or knee arthroplasty. Adjusted estimated marginal means of step count, peak cadence, overall acceleration, and machine learning–derived time spent in MVPA, derived from linear regression models, are presented in Figure 2. Unadjusted activity levels for each cohort are presented in the Supplemental Digital Content (see Supplemental Table 3, Unadjusted physical activity, http://links.lww.com/MSS/C988; Supplemental Table 4, Machine learning behavioral classification regression table, Supplemental Digital Content, http://links.lww.com/MSS/C988). Full regression results are presented in Table 2. Participants with any end-stage hip or knee arthroplasty took 1129 fewer daily steps (95% confidence interval (CI), 811–1447; $P < 0.001$), had a peak cadence of 4.8 fewer steps per minute (95% CI, 3.9–5.8; $P < 0.001$), and participated in 5.8 fewer minutes per day of MVPA (95% CI, 3.0–8.7; $P < 0.001$) compared with nonarthritic controls. Postoperative participants took 648 (95% CI, 305–990; $P < 0.001$) more daily step counts and 1.6 (95% CI, 0.5–2.6; $P = 0.004$) more steps per minute peak cadence compared with end-stage osteoarthritic participants; however, participants who had undergone any combination of hip or knee arthroplasty were less active than nonarthritic peers in terms of daily step count, peak cadence, and time spent in MVPA. No statistically significant difference in overall acceleration was observed in any comparison.

Physical activity and mobility associated with a single, unilateral hip, or knee arthroplasty. Adjusted estimated marginal means of linear regression-derived step count, peak cadence, overall acceleration, and machine learning–derived time spent in MVPA are presented in Figure 3. Full results from the linear regression models are presented in Table 3 and in the Supplemental Digital Content (Supplemental Table 5, Supplemental Digital Content, Unilateral machine learning behavioral classification regression table, http://links.lww.com/MSS/C988). After adjustment for covariates, end-stage unilateral knee osteoarthritis was associated with lower physical activity when compared with the nonarthritic reference cohort, taking 1298 fewer daily steps (95% CI, 709–1888; $P < 0.001$), a peak cadence of 6.8 (95% CI, 5.0–8.6; $P < 0.001$) fewer steps per minute, and 6.8 (95% CI, 1.5–12.0; $P = 0.012$) fewer daily minutes spent in MVPA. End-stage unilateral hip osteoarthritis was associated with taking 1108 (95% CI, 567–1648; $P < 0.001$) fewer daily steps than controls, but participants had otherwise statistically similar physical activity to their nonarthritic peers.

TABLE 1. Study cohort demographics.

Characteristic	Any Hip or Knee Arthroplasty[a]		Single-Knee Arthroplasty[b]		Single-Hip Arthroplasty[b]		
	End-Stage Arthritis[c]	12+ mo Postop[d]	End-Stage Arthritis[c]	12+ mo Postop[d]	End-Stage Arthritis[c]	12+ mo Postop[d]	Nonarthritic Cohort
Overall, *N*	514	2992	149	566	177	843	68,389
Sex, *n* (%)							
Female	301 (59)	1715 (57)	79 (53)	303 (54)	103 (58)	479 (57)	38,168 (56)
Male	213 (41)	1277 (43)	70 (47)	263 (46)	74 (42)	364 (43)	30,221 (44)
Age, median [IQR], yr	67.9 [64.0–71.4]	68.8 [64.9–72.1]	68.3 [65.0–71.6]	69.3 [65.8–72.3]	67.7 [62.7–71.6]	68.4 [64.2–71.7]	62.6 [55.4–68.1]
Ethnicity, *n* (%)							
White	509 (99)	2949 (99)	146 (98)	554 (98)	177 (100)	834 (99)	66,220 (97)
Non-White	5 (1)	43 (1)	3 (2)	12 (2)	0 (0)	9 (1)	2169 (3)
Body mass index, median [IQR], $kg \cdot m^{-2}$	28.2 [25.2–31.7]	28.3 [25.5–31.7]	28.4 [26.0–31.8]	29.2 [26.4–32.9]	26.8 [24.7–29.6]	26.7 [24.3–29.8]	25.6 [23.3–28.4]
CCI, median [IQR]	0 [0–0]	0 [0–4]	0 [0–4]	0 [0–4]	0 [0–0]	0 [0–0]	0 [0–0]
Wear season, *n* (%)							
Spring	121 (24)	653 (22)	37 (25)	113 (20)	42 (24)	175 (21)	15,800 (23)
Summer	153 (30)	821 (27)	40 (27)	158 (28)	54 (31)	231 (27)	18,071 (26)
Autumn	136 (26)	895 (30)	39 (26)	177 (31)	48 (27)	263 (31)	20,181 (30)
Winter	104 (20)	623 (21)	33 (22)	118 (21)	33 (19)	174 (21)	14,337 (21)
Education, *n* (%)							
School leaver	152 (30)	922 (31)	39 (26)	206 (36)	57 (32)	250 (30)	14,812 (22)
Further education	171 (33)	1063 (36)	58 (39)	209 (37)	40 (23)	272 (32)	22,277 (33)
Higher education	191 (37)	1007 (34)	52 (35)	151 (27)	80 (45)	321 (38)	31,300 (46)
Smoking status, *n* (%)							
Never	243 (47)	1495 (50)	78 (52)	267 (47)	87 (49)	454 (54)	40,320 (59)
Former	236 (46)	1330 (44)	60 (40)	270 (48)	81 (46)	336 (40)	23,444 (34)
Current	35 (7)	167 (6)	11 (7)	29 (5)	9 (5)	53 (6)	4625 (7)
Alcohol consumption, *n* (%)							
Never	29 (6)	204 (7)	8 (5)	40 (7)	9 (5)	46 (5)	3745 (5)
$<3\ d \cdot wk^{-1}$	233 (45)	1349 (45)	69 (46)	269 (48)	74 (42)	355 (42)	30,777 (45)
$3+\ d \cdot wk^{-1}$	251 (49)	1439 (48)	72 (48)	257 (45)	94 (53)	442 (52)	33,867 (50)
Townsend deprivation (18), *n* (%)							
Least deprived	252 (49)	1549 (52)	71 (48)	280 (49)	84 (47)	457 (54)	34,614 (51)
2nd quintile	136 (26)	671 (22)	43 (29)	125 (22)	47 (27)	181 (21)	15,373 (22)
3rd quintile	64 (12)	400 (13)	15 (10)	89 (16)	23 (13)	110 (13)	9696 (14)
4th quintile	46 (9)	276 (9)	14 (9)	59 (10)	15 (8)	66 (8)	6484 (9)
Most deprived	16 (3)	96 (3)	6 (4)	13 (2)	8 (5)	29 (3)	2222 (3)

Percentages may not add up to 100% because of rounding.
[a]Includes all participants with any combination of primary or revision knee or hip arthroplasties, excluding those who had their first arthroplasty less than 12 months before accelerometer wear (early recoverers), or more than 12 months after accelerometer wear (future first arthroplasty).
[b]Single-hip and single-knee arthroplasty cohorts are subsets of the any hip or knee arthroplasty cohort as defined in Figure 1.
[c]End-stage arthritis is considered having their first arthroplasty within 12 months after accelerometer wear.
[d]Accelerometer wear more than 12 months after the participant's first primary knee or hip arthroplasty.
CCI, Charlson Comorbidity Index.

Unilateral primary hip and knee arthroplasty were associated with 877 (95% CI, 284–1471; $P = 0.004$) and 893 (95% CI, 232–1554; $P = 0.008$) more steps than end-stage osteoarthritic participants, respectively. However, postoperative unilateral knee arthroplasty was associated with 405 (95% CI, 100–711; $P = 0.009$) fewer daily steps, a cadence of 4.2 (95% CI, 3.3–5.2; $P < 0.001$) fewer steps per minute, and 2.9 (95% CI, 0.2–5.6; $P = 0.035$) fewer daily minutes of MVPA compared with controls. Postoperative unilateral hip arthroplasty was associated with a modestly lower cadence than controls (1.5 (95% CI, 0.7–2.3;

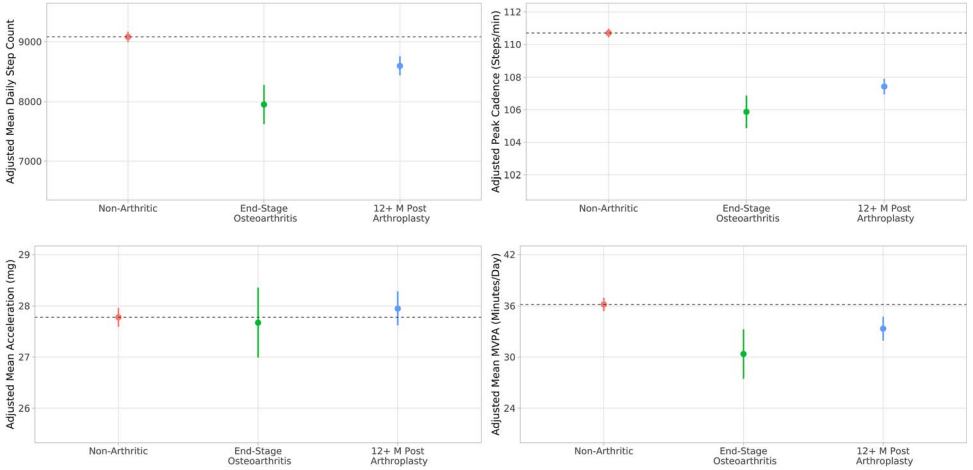

FIGURE 2—Model-adjusted activity for any hip or knee osteoarthritis and arthroplasty. Estimated marginal means and 95% CIs of activity and mobility metrics in participants who are nonarthritic, end-stage osteoarthritic, and more than 12 months postoperative from first primary knee or hip arthroplasty. Metrics are adjusted for age, sex, body mass index, season, Charlson Comorbidity Index, education, ethnicity, alcohol consumption, and smoking status.

TABLE 2. Linear regression–adjusted differences between nonarthritic participants and participants with any combination of hip and/or knee arthroplasties in primary activity measures.

Metric	Reference Cohort	End-Stage Knee and/or Hip Osteoarthritis (n = 514)	12+ mo after First Knee or Hip Arthroplasty (n = 2992)
Median daily step count (steps per day)	Nonarthritic (n = 68,389)	−1129 [−1447 to −811] (P < 0.001)	−482 [−619 to −345] (P < 0.001)
	End-stage knee and/or hip osteoarthritis (n = 514)		648 [305 to 990] (P < 0.001)
Peak Cadence (steps per minute)	Nonarthritic (n = 68,389)	−4.8 [−5.8 to −3.9] (P < 0.001)	−3.3 [−3.7 to −2.9] (P < 0.001)
	End-stage knee and/or hip osteoarthritis (n = 514)		1.6 [0.5 to 2.6] (P = 0.004)
Overall acceleration (mg)	Nonarthritic (n = 68,389)	−0.1 [−0.8 to 0.6] (P = 0.753)	0.2 [−0.1 to 0.5] (P = 0.238)
	End-stage knee and/or hip osteoarthritis (n = 514)		0.3 [−0.4 to 1.0] (P = 0.461)
Moderate-to-vigorous activity (min·d^{-1})	Nonarthritic (n = 68,389)	−5.8 [−8.7 to −3.0] (P < 0.001)	−2.8 [−4.1 to −1.6] (P < 0.001)
	End-stage knee and/or hip osteoarthritis (n = 514)		3.0 [−0.1 to 6.0] (P = 0.055)

Estimate [95% CI] in activity metrics adjusted for age, sex, body mass index, season, Charlson Comorbidity Index, education, ethnicity, alcohol consumption, and smoking status. A negative difference indicates lower activity in the cohort of interest relative to the reference cohort.

P < 0.001) steps per minute), but these participants were otherwise equivalent to nonarthritic peers in terms of activity and mobility. No difference in physical activity was observed between any cohorts in terms of overall daily light activity, sedentary behavior, or sleep time.

DISCUSSION

Our cross-sectional study indicated significantly higher activity in terms of daily step count after hip and knee arthroplasty when compared with participants with end-stage hip osteoarthritis. As a result, participants who have undergone surgical intervention demonstrate only modestly lower or equivalent physical activity compared with their nonarthritic peers across metrics, with the most room for improvement seen in postoperative knee arthroplasty cohorts in terms of daily step count, peak cadence, and time spent in MVPA. We found that within the UK Biobank cohort, daily step count captured the biggest difference in activity levels across study groups, whereas other physical activity metrics, including overall acceleration and time usage behaviors, provided fewer differential insights.

The first objective of this study was to assess the effect of end-stage knee and hip arthritis on physical activity compared with a nonarthritic peer group. We found that participants with any end-stage hip or knee osteoarthritis took 12% fewer steps per day, had a 4% slower peak cadence, and spent 16% fewer minutes per day in MVPA compared with nonarthritic peers. When assessing activity in participants with single-site arthritis, both knee and hip arthritis were associated with lower daily steps, lower peak cadence, and less time spent in MVPA compared with nonarthritic controls. Prior, smaller studies of objectively measured physical activity in end-stage osteoarthritic patients show similar patterns, yet greater differences, with end-stage hip or knee osteoarthritis associated with 20%–35% fewer steps and active minutes than health controls (19–21).

When comparing postoperative unilateral knee and hip arthroplasty cohorts with end-stage arthritic cohorts, our results indicate 11% higher daily step count in both unilateral knee and hip arthroplasty cohorts. Prior evidence as to whether physical activity increases for the average patient after surgery has been mixed, as most historical investigations of physical activity in patients with hip and knee arthroplasty have been conducted using self-reported questionnaires limited by well-documented methodological biases (1,3). In these cases, many patients report increased physical activity and functional improvement on patient-reported outcome measures; however, a majority of studies using objectively measured activity describe only minimal gains in postoperative activity and step count in small patient populations (1,22,23). In a longitudinal study using a consumer-grade activity tracker, Christensen et al. (5) reported

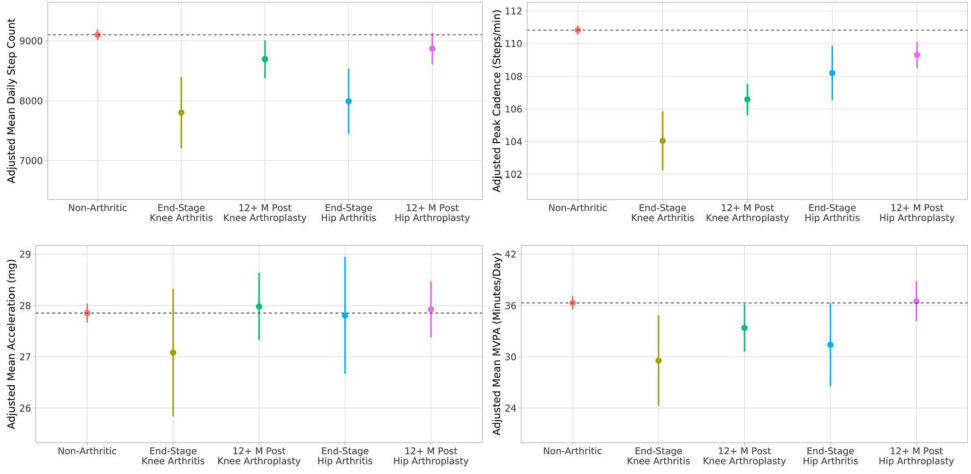

FIGURE 3—Model-adjusted activity for unilateral hip or knee osteoarthritis and arthroplasty. Estimated marginal means and 95% CIs of activity and mobility metrics in participants who are nonarthritic, have end-stage knee osteoarthritis, are more than 12 months postoperative from unilateral primary knee arthroplasty, have end-stage hip osteoarthritis, or are more than 12 months postoperative from unilateral primary hip arthroplasty. Metrics are adjusted for age, sex, body mass index, season, Charlson Comorbidity Index, education, ethnicity, alcohol consumption, and smoking status.

TABLE 3. Linear regression–adjusted differences between nonarthritic participants and clinically defined unilateral hip and knee participant cohorts in primary activity measures.

Metric	Reference Cohort	End-Stage Knee Osteoarthritis (n = 149)	12+ mo after Knee Arthroplasty (n = 566)	End-Stage Hip Osteoarthritis (n = 177)	12+ mo after Hip Arthroplasty (n = 843)
Median daily step count (steps per day)	Nonarthritic (n = 68,389)	−1298 [−1888 to −709] (P < 0.001)	−405 [−711 to −100] (P = 0.009)	−1108 [−1648 to −567] (P < 0.001)	−230 [−480 to 20] (P = 0.071)
	End-stage knee osteoarthritis (n = 149)		893 [232 to 1554] (P = 0.008)	191 [−608 to 989] (P = 0.640)	1068 [430 to 1706] (P = 0.001)
	12+ mo after knee arthroplasty (n = 566)			−702 [−1321 to −83] (P = 0.026)	175 [−216 to 566] (P = 0.380)
	End-stage hip osteoarthritis (n = 177)				877 [284 to 1471] (P = 0.004)
Peak cadence (steps per minute)	Nonarthritic (n = 68,389)	−6.8 [−8.6 to −5.0] (P < 0.001)	−4.2 [−5.2 to −3.3] (P < 0.001)	−2.6 [−4.3 to −1.0] (P = 0.002)	−1.5 [−2.3 to −0.7] (P < 0.001)
	End-stage knee osteoarthritis (n = 149)		2.5 [0.5 to 4.6] (P = 0.013)	4.2 [1.7 to 6.6] (P < 0.001)	5.3 [3.3 to 7.2] (P < 0.001)
	12+ mo after knee arthroplasty (n = 566)			1.6 [−0.3 to 3.5] (P = 0.092)	2.7 [1.5 to 3.9] (P < 0.001)
	End-stage hip osteoarthritis (n = 177)				1.1 [−0.7 to 2.9] (P = 0.236)
Overall acceleration (mg)	Nonarthritic (n = 68,389)	−0.8 [−2.0 to 0.5] (P = 0.216)	0.1 [−0.5 to 0.8] (P = 0.693)	−0.0 [−1.2 to 1.1] (P = 0.935)	0.1 [−0.4 to 0.6] (P = 0.788)
	End-stage knee osteoarthritis (n = 149)		0.9 [−0.5 to 2.3] (P = 0.199)	0.7 [−0.9 to 2.4] (P = 0.391)	0.8 [−0.5 to 2.2] (P = 0.212)
	12+ mo after knee arthroplasty (n = 566)			−0.2 [−1.5 to 1.1] (P = 0.790)	−0.1 [−0.9 to 0.8] (P = 0.892)
	End-stage hip osteoarthritis (n = 177)				0.1 [−1.1 to 1.4] (P = 0.851)
Moderate-to-vigorous activity (min·d^{-1})	Nonarthritic (n = 68,389)	−6.8 [−12.0 to −1.5] (P = 0.012)	−2.9 [−5.6 to −0.2] (P = 0.035)	−4.9 [−9.7 to −0.1] (P = 0.046)	0.2 [−2.0 to 2.4] (P = 0.870)
	End-stage knee osteoarthritis (n = 149)		3.8 [−2.0 to 9.7] (P = 0.200)	1.9 [−5.3 to 9.0] (P = 0.609)	6.8 [1.3 to 12.6] (P = 0.012)
	12+ mo after knee arthroplasty (n = 566)			−2.0 [−7.5 to 3.5] (P = 0.479)	3.1 [−0.4 to 6.6] (P = 0.080)
	End-stage hip osteoarthritis (n = 177)				5.1 [−0.2 to 10.4] (P = 0.059)

Difference [95% CI] in activity metrics adjusted for age, sex, body mass index, season, Charlson Comorbidity Index, education, ethnicity, alcohol consumption, and smoking status. A negative difference indicates lower activity in the cohort of interest relative to the reference cohort.

a return to preoperative step count within 1 month after unilateral knee arthroplasty in 1005 total knee arthroplasty patients, culminating in approximately 40% more daily steps at 1-yr follow-up. This increase is substantially higher than studies of previous cohorts and may be a result of selection bias by including only participants who owned Apple Watch–compatible iPhones at targeted surgical centers. A more moderate difference in activity levels between postoperative and end-stage arthritic cohorts was observed in the current study, which may result, in part, from the UK Biobank drawing health records from surgical interventions performed across the breadth of public health care facilities. Importantly, orthopedic practice has undergone changes over the past decade since the UK Biobank accelerometer data were collected. Day-case arthroplasty, enhanced recovery protocols, and exercise-centered treatment plans have all become increasingly common in recent years in an effort to improve perioperative care and increase postoperative patient activity. Further investigation is needed to characterize the effectiveness of these initiatives to improve postoperative activity and to determine if the findings in the current study reflect the physical behavior of the current generation of lower limb arthroplasty patients.

An important target outcome for successful lower limb arthroplasty is the restoration of joint mobility, enabling the potential of increased physical activity and improved overall patient health compared with before surgical intervention. Physical activity is well correlated with health outcomes, and an increase of 1000 steps per day has been attributed to a lower risk of cardiovascular disease and all-cause mortality (24). Compared with their nonarthritic peers, postoperative unilateral knee arthroplasty was associated with taking 4% fewer daily steps, 4% slower cadence, and 8% less time in MVPA. Conversely, postoperative unilateral hip arthroplasty was associated with equivalent daily step count, peak cadence, and levels of MVPA compared with nonarthritic controls. Other comparisons have been drawn in terms of physical activity levels between postoperative hip or knee arthroplasty patients and nonarthritic controls, reporting significantly lower activity in these patients compared with their peers (25–30). Walker et al. (28) and Kersten et al. (30) reported that activity in postoperative knee patients may still be up to 20% less than in healthy controls. Whereas most prior studies of physical activity in orthopedic populations to healthy controls have generally matched only on age and sex (1,27), the current analysis adjusts for other confounders of activity, including body mass index, education, alcohol intake, smoking status, and medical comorbidities (8).

In this study, daily step count, time spent in MVPA, and peak cadence metrics demonstrated sensitivity to lower limb osteoarthritis and surgical intervention, yet no differences in physical activity were observed between any cohorts when comparing overall acceleration magnitude. Although overall acceleration is a validated surrogate for general activity level (31), daily step count and physical activity energy expenditure have also been used as validated metrics in the UK Biobank to quantify overall participant activity levels and its association with all-cause mortality (9,32). As observed in the current

analysis, the inclusion of mobility-centric metrics like step count and peak cadence may enable more nuanced analysis in certain populations compared with overall acceleration and physical activity energy expenditure. This may imply that orthopedic surgical intervention affects overall mobility but does not greatly affect behavioral patterns of sleep, sedentary time, and light activity. In the clinical setting, an increase in walking activity reflects a primary aim of lower limb arthroplasty, the restoration of joint function enabling return to mobility-related activities of daily living. In future studies, the inclusion of step metrics and machine learning classification of behaviors, such as time spent in MVPA, may elucidate insights into physical activity not distinguished by acceleration alone.

This study incorporates a highly accurate free-living validated step-counting algorithm designed from the same research-grade accelerometer as used in the UK Biobank; however, some caution may need to be taken when applying a step detection algorithm trained on health participants to orthopedic clinical populations (18,33,34) with abnormal gait, as up to 16% of arthroplasty patients have at least some dependence on walking aids (35). Because assistance is generally minor (35–37), usually consisting of a single cane (37), the effect on step count accuracy will be small compared with more substantial gait aids (18). Lower step count in participants with end-stage osteoarthritis may include some underestimation bias due to walking aid use. Even so, this increased postoperative step count retains and supports the overall conclusion of improved functional mobility (increased activity and/or reduced levels of aid) in postoperative arthroplasty patients. Of note, the UK Biobank health record linkage lacks data on privately accessed medical services; thus, an unknown level of missing operative records from private health care facilities is unaccounted for, particularly within the nonarthritic control population. The use of additional *ICD* diagnostic codes alongside the conservative exclusion of any participants with self-reported knee or hip pain was incorporated to minimize the inclusion of hidden operative cases within the cohort. Furthermore, to preserve statistical power, we did not differentiate unicompartmental knee arthroplasty from total knee arthroplasty or hip resurfacing from total hip arthroplasty when creating study cohorts using the OPCS codes. These less invasive procedures typically demonstrate quicker recovery and may have different activity patterns than standard total knee and hip arthroplasty. The current study is a cross-sectional analysis and does not enable patient-level assessment of physical activity before and after knee or hip arthroplasty. Through physical activity monitoring and digital health interventions, opportunities exist for further carefully designed longitudinal evaluation of postoperative recovery to increase activity levels, improve mobility, and identify patient outliers in need of further intervention.

CONCLUSIONS

This is the largest investigation of wearable-measured physical activity in hip or knee arthroplasty patients to date, with well-established health record linkage and detailed demographic data allowing for adjustment across multiple confounders of physical activity. The results highlight the significantly higher levels of activity in postoperative compared with end-stage osteoarthritic cohorts, with unilateral knee and hip arthroplasty patients taking approximately 900 steps per day more than respective end-stage arthritic peers. However, postoperative knee arthroplasty was associated with lower physical activity compared with nonarthritic peers, providing motivation for further work in developing rehabilitation programs focused on improving physical activity, particularly in knee patients.

This research was funded in whole or in part by the Wellcome Trust (223100/Z/21/Z). A. D. and S. R. S. are supported by the Wellcome Trust. A. D., S. R. S., and S. K. are supported by Health Data Research UK, an initiative funded by UK Research and Innovation, Department of Health and Social Care (England), and the devolved administrations. A. D. is further supported by Novo Nordisk, Swiss Re and by the BHF Centre of Research Excellence (grant number RE/18/3/34214). S. R. S. is further supported by the University of Oxford Clarendon Fund. S. K. is further supported by Amgen and UCB BioPharma outside of the scope of this work. Computational aspects of this research were funded by the National Institute for Health Research Oxford Biomedical Research Centre with additional support from Health Data Research UK and the Wellcome Trust Core Award (grant number 203141/Z/16/Z). The views expressed are those of the authors and not necessarily those of the NHS, the National Institute for Health Research, or the Department of Health. For the purpose of open access, the authors have applied a Creative Commons Attribution (CC-BY) license to any Author Accepted Manuscript version arising. The results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation. The results of the present study do not constitute endorsement by the American College of Sports Medicine.

No direct project funding was received. Indirect funding support is listed previously, with no funder involvement in study design, data collection, analysis, interpretation or writing. This research has been conducted using the UK Biobank Resource under Application Number 59070.

Availability of data and materials: All data used in this study were collected or derived from the UK Biobank. Our open-source accelerometer processing tool to calculate validated step count from raw accelerometry data is available for use at https://github.com/OxWearables/stepcount.

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