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Patients with High Pre-Operative Physical Activity Take Longer to Return to Baseline

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Abstract: Patients with end-stage osteoarthritis are recommended to engage in physical activity (PA) to reduce pain and improve function but may avoid PA due to joint pain. Our goal was to investigate patient-reported outcomes and objective mobility metrics (step counts) in total hip arthroplasty (THA) patients as a function of pre-operative PA levels. In total, 1647 patients enrolled in a multicenter prospective cohort study investigating a smartphone-based care management platform for self-directed rehabilitation that underwent THA and were included in analysis. The entire cohort's step count was divided into quartiles to categorize patients with low, moderate, and high baseline PA. Outcomes including pain, EQ-5D-5L, HOOS JR, and step counts were compared according to activity group by ANOVA. Pre-operative pain scores were lowest, with smallest improvements, in the high-baseline PA group. Low-PA patients demonstrated the greatest improvements in EQ-5D-5L, while changes in EQ-VAS, HOOS JR, and satisfaction were similar between groups. Low- and moderate-PA patients increased physical activity by six weeks, reaching 180% and 114% of pre-operative steps; high-PA patients did not return to full step counts until one-year post-operation. Patients who perform high levels of PA undergoing THA report lower levels of pain and higher function pre-operatively but may appreciate less improvement in PA up to one year post-operatively. These results may be helpful in appropriate counseling of patient expectations prior to surgery.

Keywords: mobile health; total hip arthroplasty; physical activity; step count

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1. Introduction

The prevalence of hip osteoarthritis (OA) has been estimated to be 7.95% in North America [1], which may owe in part to the aging population and increasing prevalence of obesity [2]. Accordingly, the incidence of total hip arthroplasty (THA) has been predicted to increase to 635,000 procedures annually by 2030 in the United States [3]. While evidence has suggested that physical activity (PA) in patients with OA may improve both joint pain and function, as well as other comorbid conditions and quality of life [4], the associated discomfort may limit these patients from achieving recommended levels of PA. Authors have reported that the majority of patients with OA do not meet guideline recommendations for daily activity [5,6], performing less PA than age-matched subjects without OA [7]. In addition, several reports have suggested that these patients spend the majority of their time in sedentary behaviors [8–10], which has been shown to significantly impact the risk of morbidity and mortality in adult populations [11].

THA is a highly successful procedure resulting in decreased pain and improved joint function and quality of life post-operatively, with high rates of patient-reported satisfaction [12,13]. Authors suggest that delay of surgical intervention is associated with waste of healthcare resources [14]; patients appear to be undergoing the procedure earlier and at younger ages [15,16]. THA patients expect to return to pre-operative levels of activity, with active patients reporting higher expectations than inactive patients, often expressing the expectation to return to sports [17]. One report indicated that some patients desire returning to a level of athleticism achieved only prior to the onset of OA [18]. The evolution of implant designs have led to fewer surgeon-recommended activity and sports restrictions following THA [19], with evidence that high activity is associated with improved implant survival [20,21]. Despite this, many patients report self-imposed activity restrictions due to anxiety regarding injury or damage to implants, rather than limitations associated with joint pain post-operatively [19,22].

While THA has proven successful in ameliorating pain and returning function as measured by joint-specific patient-reported outcome measures (PROMs), the current literature presents mixed results with regards to whether or not physical activity actually increases post-operatively [6,23]. Investigations utilizing subjective, self-reported measures of activity suggest that patients appreciate improved levels of PA compared to pre-operative levels [24,25]. However, patients who were highly active prior to surgery have reported decreased activity up to two years post-operation, while patients who were considered inactive at baseline reported significantly increased activity after THA [25,26]. Though some have reported improved PA post-operatively via objective data [27,28], others have reported decreases or insignificant changes [10,29,30]. Studies that focus on the correlation of self-reported activity or PROMs and objective measures, as collected by wearable activity monitors, suggest that subjective and objective data exhibit low-to-moderate correlations [31–33]. We are unaware of any reports that have compared objective PA changes as a function of baseline activity levels. In this study, we aimed to determine whether recovery of objective PA as measured by step counts differed between patients with varying levels of activity prior to THA. In addition, joint-specific PROMs, generic health-related quality of life (HRQoL), pain, and satisfaction were compared between activity levels to further characterize recovery by baseline activity.

2. Materials and Methods

A secondary analysis of a multicenter prospective longitudinal cohort study was performed. Patients at least 18 years of age and undergoing THA for treatment of end-stage osteoarthritis were assessed for eligibility in a trial investigating the use of a smartphone-based care management platform with smartwatch (mymobility®, Zimmer Biomet, Warsaw, IN, USA) for self-directed rehabilitation following arthroplasty (Clinicaltrials.gov (accessed on 1 January 2023) identifier NCT03737149). The application provides arthroplasty-specific education pre- and post-operatively, as well as video-guided exercises and delivery of appropriate PROMs questionnaires at specified time intervals up to one year following surgery. All patients were required to own an Apple iPhone® (Apple Inc., Cupertino, CA, USA) capable of pairing with the Apple Watch® (Apple Inc., Cupertino, CA, USA), which was provided to all enrolled participants. Participants were also required to be ambulatory with no more than a single crutch or cane pre-operatively and were excluded if undergoing bilateral THA (simultaneous or staged <90 days), participating in any other surgical intervention, physical therapy, or pain management studies, or if known to be a current drug or alcohol abuser. IRB approval was obtained prior to the beginning of enrollment; all participants provided written informed consent. A total of 1647 patients who underwent THA at 24 sites between December 2018 and July 2022 were eligible to be included in this analysis and volunteered to participate.

Participants were requested to download the mobile application at least two weeks prior to surgical intervention to allow for continuous passive collection of pre-operative activity (daily step counts). Objective mobility metrics were collected by the application for up to 425 days post-operatively or until study exit or withdrawal. Average daily step counts were calculated over the two-week pre-operative period and over a one-week period centered at each interval in the post-operative periods. Post-operative activity was only included if data were provided in at least four of seven days in these periods.

Patients completed general and joint-specific PROMs including EQ-5D-5L, EQ-VAS, and Hip Disability and Osteoarthritis Outcomes–Joint Replacement (HOOS JR) pre-operatively through one year post-operatively. The HOOS JR is a validated instrument for evaluation of hip replacement outcomes combining pain, symptoms, and functional limitations ranging from 0 to 100 points, where 0 indicates the worst level of pain and function and 100 reflects perfect joint health. The pain numeric rating score (NRS, 0–10 points) and a satisfaction questionnaire based on the Knee Society Score (KSS) satisfaction subscale (0–40 points), which collects information about satisfaction with the affected joint during daily activities including sitting, lying in bed, getting out of bed, performing light household duties, and performing recreational activities, were completed pre-operatively and at one and three months post-operatively.

Average daily step counts over the entire cohort were assessed to categorize patients' relative activity levels before surgical intervention. Participants whose step counts were in the bottom quartile were labeled as low activity, the middle two quartiles (25th–75th percentile) were categorized as moderate activity, and the top quartile categorized as high activity. Baseline characteristics and post-operative outcomes including PROMs, satisfaction, pain, and steps counts were compared between these categories by one-way ANOVA with ad hoc Tukey pairwise comparisons. All outcome measures were also compared in this manner as a function of change in score from baseline, as were the percentage of steps performed through one year compared to pre-operative. To investigate changes in step counts for each individual pre-operative activity level, paired t tests were completed. Only patients who completed surveys or provided adequate step count data (four of seven days in each period investigated) were included in evaluations of change from baseline or paired t tests. All continuous variables are presented as mean ± standard deviation (SD); categorical data are presented as counts and percent and compared by chi-square analysis. Analyses were performed with SAS Enterprise Guide v7.1 (2014 SAS Institute Inc., Cary, NC, USA); p values < 0.05 were considered statistically significant.

3. Results

The average age over the entire cohort was 61.9 ± 10.4 years. In total, 51.6% were female with average BMI 29.4 ± 6.0 (Table 1). The median pre-operative step count in all participants was 5151 ± 2973 steps per day (Table 2). The average daily step counts in the low-, moderate-, and high-activity groups were 1953, 4745, and 9162, respectively. Age and BMI varied over activity groups, where lower activity groups were older with higher BMI; however, gender distribution did not vary by groupings.

Table 1. Baseline patient characteristics, including age, body mass index (BMI, kg/m^2), and sex by pre-operative activity levels. Continuous variables are presented as mean ± standard deviation (SD), with number of participants providing data and range (min–max). Categorical variables are presented as number and percent.

	All Activity Levels	Low Pre-Operative Activity	Moderate Pre-Operative Activity	High Pre-Operative Activity	p Value
Age mean ± SD (n, min–max)	61.9 ± 10.4 (1612, 19–91)	65.1 ± 10.2 (403, 24–91)	61.4 ± 10.0 (806, 19–87)	59.4 ± 10.6 (59, 23–81)	<0.0001
BMI mean ± SD (n, min–max)	29.4 ± 6.0 (1606, 16.8–55.6)	31.5 ± 6.7 (402, 18.6–53.2)	29.6 ± 5.6 (804, 16.8–55.6)	27.1 ± 5.1 (400, 16.9–47.1)	<0.0001
Sex—female n (%)	832 (51.6)	223 (55.3)	404 (50.1)	205 (50.9)	0.22

Table 2. Average step counts over cohort and by pre-operative activity levels, presented as mean ± standard deviation (SD), with number of participants and range (min–max) at each time point investigated (pre-operative through one-year post-arthroplasty). Percent recovery was calculated by dividing the number of average daily steps at each interval by the participants' baseline pre-operative average daily step counts.

	All Activity Levels Mean ± SD (n, Min–Max)	**Low Pre-Operative Activity Mean ± SD (n, Min–Max)**	**Moderate Pre-Operative Activity Mean ± SD (n, Min–Max)**	**High Pre-Operative Activity Mean ± SD (n, Min–Max)**	***p* Value**
Pre-operative step count	5151 ± 2973 (1612, 88–26,151)	1953 ± 739 (403, 88–3059)	4745 ± 1026 (806, 3059–6682)	9162 ± 2462 (403, 6706–26,151)	<0.0001
4 weeks	4966 ± 2960 (1557, 40–28,911)	2780 ± 1932 (382, 40–11,506)	4763 ± 2337 (782, 92–28,911)	7494 ± 3023 (393, 149–19,565)	<0.0001
6 weeks	5483 ± 3035 (1529, 32–24,635)	3104 ± 1990 (369, 32–11,506)	5301 ± 2406 (773, 292–24,635)	8113 ± 2494 (387, 616–19,056)	<0.0001
3 months	6016 ± 3328 (1368, 79–33,094)	3567 ± 2483 (325, 79–14,915)	5768 ± 2435 (680, 239–21,729)	8672 ± 3551 (363, 295–33,094)	<0.0001
6 months	6167 ± 3474 (1305, 19–21,196)	3414.6 ± 2289 (302, 19–16,206)	5963 ± 2754 (657, 58–17,408)	8954 ± 3480 (346, 729–21,196)	<0.0001
12 months	6244 ± 3634 (927, 193–25,282)	3563 ± 2557 (209, 193–17,792)	5913 ± 2807 (464, 327–18,484)	9056 ± 3804 (254, 828–25,282)	<0.0001
Percent recovery					
4 weeks	111.8 ± 89.8 (1557, 1.5–1653.0)	159.4 ± 149.2 (382, 6.5–1653.0)	102.8 ± 55.8 (782–2.9–752.0)	83.3 ± 31.1 (393, 1.5–241.0)	<0.0001
6 weeks	124.1 ± 98.2 (1529, 6.8–1873.0)	180.5 ± 166.2 (369, 12.4–1873.0)	114.4 ± 57.3 (773, 6.8–640.8)	89.9 ± 29.5 (387, 8.8–248.5)	<0.0001
3 months	137.3 ± 116.8 (1368, 3.9–1900.0)	211.4 ± 204.6 (325, 3.9–1900.0)	124.1 ± 56.0 (680, 6.4–528.3)	95.7 ± 33.8 (363, 4.1–252.0)	<0.0001
6 months	137.4 ± 113.8 (1305, 1.4–1609.7)	203.0 ± 199.4 (302, 7.6–1609.7)	127.6 ± 63.3 (657, 1.4–519.0)	98.9 ± 35.6 (346, 10.4–265.4)	<0.0001
12 months	138.8 ± 130 (927, 6.9–2135.5)	215.5 ± 237.4 (209, 8.9–2135.5)	125.4 ± 63.7 (464, 6.9–589.2)	100.2 ± 37.6 (254, 11.8–303.9)	<0.0001

Average daily steps at specified intervals though one year post-operatively were compared between pre-operative activity groups (Table 2). Participants who performed the highest quartile of steps prior to THA continued to perform more steps at every timepoint investigated. However, considering recovery of step counts as a percentage of the average performed before surgery, the participants categorized as low- and moderate-activity groups exceeded their pre-operative steps by 4 weeks post-operation, performing 159% and 103% of their baseline activity, respectively, while high activity patients achieved 83% of their pre-operative steps at this time. Low pre-operative PA participants doubled their pre-operative steps at three months, moderate activity participants returned to 124% of average daily steps, and the high activity group did not reach pre-operative levels, performing 96% of their pre-operative average steps (Figure 1). While low- and moderate-activity groups both exceeded pre-operative activity levels by three months post-operation, those with the highest pre-operative counts did not achieve this goal until one year post-operatively.

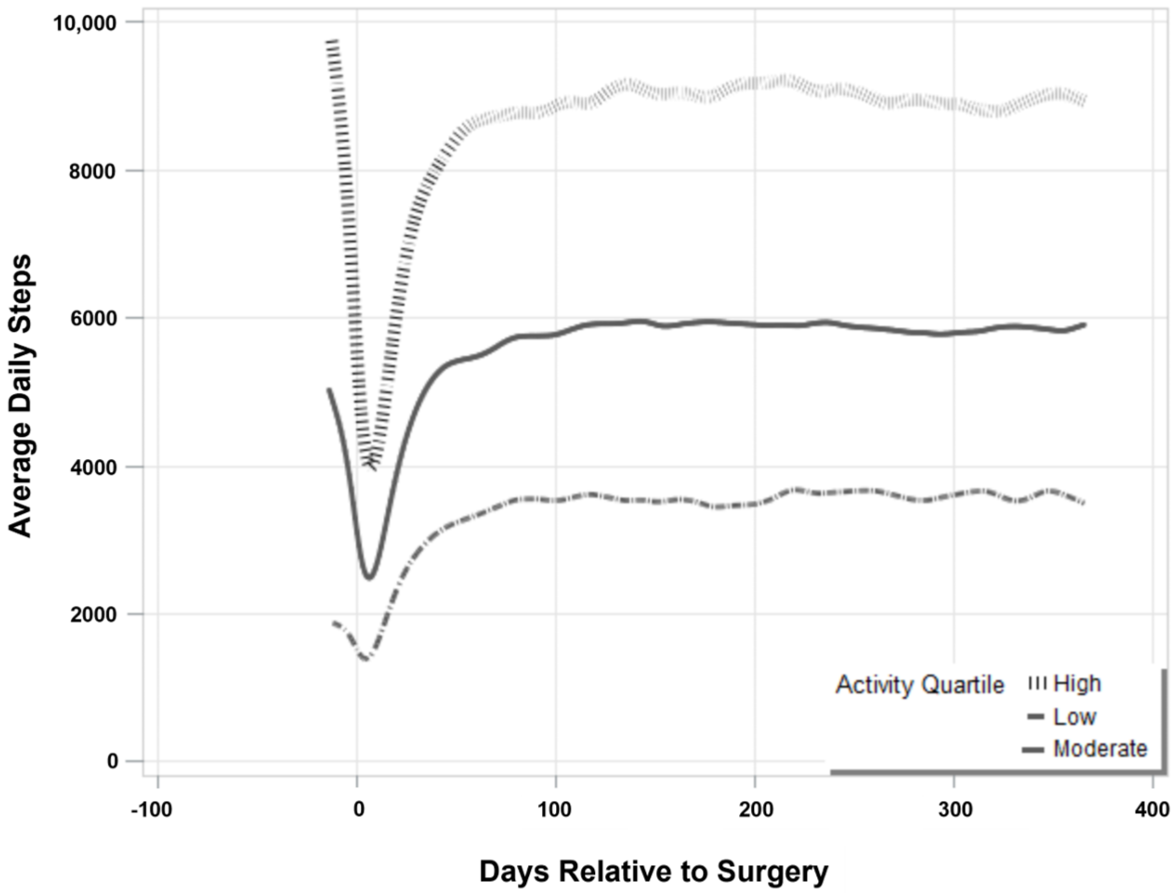

Figure 1. Step count recovery curves of total hip arthroplasty patients by baseline activity quartiles.

Paired *t* tests at each of these time points indicated that the change in low pre-operative activity participants' step counts reached significant improvement by four weeks post-operatively (Table 3) and improvements in daily step counts appeared to plateau around 3 months post-operation. Moderate activity participants did not significantly improve steps counts until six weeks after surgery, while highly active participants continued to demonstrate significantly reduced step counts through 6 months post-operation.

Table 3. Paired *t* tests indicating change in steps from pre-operative to each follow up period, presented as mean ± standard deviation (SD) with number of participants (n) and range (min–max) by pre-operative activity groups.

Step Count Change from Pre-operative	Low Pre-Operative Activity Mean ± SD (n, Min–Max)	*p* Value	Moderate Pre-Operative Activity Mean ± SD (n, Min–Max)	*p* Value	High Pre-Operative Activity Mean ± SD (n, Min–Max)	*p* Value
4 weeks	805 ± 1885 (382, −2667–9352)	<0.0001	15 ± 2337 (782, −5124–25,066)	0.86	−1687 ± 3180 (393, −22,705–10,659)	<0.0001
6 weeks	1132 ± 1944 (369, −2164–10,715)	<0.0001	560 ± 2369 (772, −4884–20,791)	<0.0001	−1082 ± 2971 (386, −19,355–11,224)	<0.0001
3 months	1603 ± 2447 (325, −2523–13,908)	<0.0001	1014 ± 2369 (680, −5866–17,566)	<0.0001	−492 ± 3125 (363, −10,156–19,962)	0.003
6 months	1453 ± 2271 (299, −2258–15,199)	<0.0001	1176 ± 2676 (652, −5496–13,146)	<0.0001	−219 ± 3293 (342, −18,044–12,498)	<0.0001
12 months	1614 ± 2556 (207, −2275–16,785)	<0.0001	1117 ± 2730 (462, −6213–15,347)	<0.0001	−58 ± 3274 (251, −12,027–15,409)	0.78

Function as measured by the HOOS JR varied by activity groups pre-operatively, though the differences between groups does not meet previously reported minimal clinically important difference (MCID) [34]. Participants in the low-activity group reported the lowest hip function prior to surgery, increasing among higher activity level participants (50.09 vs 52.63 vs 56.18, $p < 0.0001$, all pairwise comparisons $p < 0.05$). HOOS JR scores continued to vary between groups through the entire study period following THA; however, these differences did not meet MCID and were not clinically important (Table 4). Those in the low and moderate pre-operative PA groups reported greater improvements over baseline at one month after surgery. Changes reported were similar at 3 and 6 months following THA, but met statistical significance at one year post-operatively, where high pre-operative activity patients reported slightly lower improvements on HOOS JR.

Table 4. HOOS JR scores and changes from baseline in the overall cohort and by pre-operative activity levels. All data are presented as mean ± standard deviation (SD) with number of participants providing data at each interval (n) and range (min–max).

KOOS JR	All Activity Levels Mean ± SD (n, Min–Max)	Low Pre-Operative Activity Mean ± SD (n, Min–Max)	Moderate Pre-Operative Activity Mean ± SD (n, Min–Max)	High Pre-Operative Activity Mean ± SD (n, Min–Max)	*p* Value
Pre-operative	52.90 ± 12.9 (1571, 0–100)	50.09 ± 13.67 (390, 0–92.34)	52.63 ± 12.60 (784, 0–100)	56.18 ± 11.99 (397, 8.10–92.34)	<0.0001
1 month	73.43 ± 12.34 (1555, 20.81–100)	71.30 ± 12.89 (383, 23.74–100)	74.06 ± 12.32 (780, 20.81–100)	74.24 ± 11.61 (392, 36.36–100)	0.0005
3 months	81.98 ± 13.17 (1453, 20.81–100)	79.98 ± 13.44 (353, 39.90–100)	81.97 ± 13.04 (723, 20.81–100)	83.86 ± 12.94 (377, 39.90–100)	0.0004
6 months	86.17 ± 13.19 (1358, 32.74–100)	84.69 ± 13.72 (332, 32.74–100)	86.07 ± 13.09 (675, 36.36–100)	87.77 ± 12.71 (351, 46.65–100)	0.009
12 months	89.88 ± 12.17 (1081, 43.34–100)	88.23 ± 12.85 (259, 49.86–100)	90.41 ± 11.73 (528, 43.34–100)	90.38 ± 12.24 (294, 43.34–100)	0.044
Δ1 month	20.38 ± 15.2 (1530, −30.53–74.9)	20.93 ± 15.84 (373, −15.89–70.99)	21.34 ± 14.83 (767, −24.18–74.9)	17.97 ± 15.08 (390, −30.53–71.54)	0.001
Δ3 months	28.99 ± 16.02 (1432, −41.01–85.26)	29.5 ± 16.94 (344, −7.08–76.71)	29.31 ± 15.62 (712, −41.01–85.26)	27.93 ± 15.88 (376, −27.68–71.54)	0.32
Δ6 months	32.97 ± 15.76 (1338, −26.33–84.37)	33.83 ± 16.63 (325, −13.92–84.37)	33.33 ± 15.53 (663, −26.33–84.37)	31.48 ± 15.29 (350, −14.55–79.2)	0.11
Δ12 months	36.75 ± 16.64 (1070, −21.94–100)	37.64 ± 15.92 (256, −18.87–70.99)	37.77 ± 15.06 (521, −21.91–100)	34.15 ± 16.14 (293, −18.01–72.45)	0.004

Pre-operative pain scores were highest in the low-activity group (6.38) and lowest in the high-activity group (5.62, $p < 0.0001$), with pairwise comparisons $p < 0.05$ except in low vs medium groups. At one month following surgery, patient-reported pain was similar among the activity groups (Table 5). However, reduction in pain at this time was also largest in those with moderate pre-operative activity, differing only from the high-PA group on pairwise comparison. At three months post-operatively, pain remained similar between groups, with high pre-operative activity patients reporting the smallest overall reduction.

Table 5. General and health-related quality of life patient reported outcome measures. All data are presented as mean ± standard deviation (SD) with number of participants providing data at each interval (n) and range (min–max).

	All Activity Levels Mean ± SD (n, Min–Max)	**Low Pre-Operative Activity Mean ± SD (n, Min–Max)**	**Moderate Pre-Operative Activity Mean ± SD (n, Min–Max)**	**High Pre-Operative Activity Mean ± SD (n, Min–Max)**	***p* Value**
Pain					
Pre-operative	6.05 ± 1.97 (1457, 0–10)	6.38 ± 1.90 (354, 1–10)	6.13 ± 1.98 (723, 0–10)	5.62 ± 1.94 (380, 0–10)	<0.0001
30 days	2.58 ± 2.00 (1339, 0–10)	2.75 ± 2.11 (333, 0–9)	2.51 ± 1.98 (662, 0–10)	2.54 ± 1.94 (344, 0–9)	0.19
90 days	1.62 ± 1.95 (1251, 0–10)	1.75 ± 2.11 (284, 0–9)	1.53 ± 1.83 (629, 0–10)	1.67 ± 2.02 (338, 0–9)	0.25
Δ 30 days	−3.42 ± 2.55 (1316, −10–5)	−3.60 ± 2.65 (327, −9–4)	−3.52 ± 2.52 (650, −10–5)	−3.03 ± 2.48 (339, −9–3)	0.005
Δ 90 days	−4.35 ± 2.63 (1162, −10–9)	−4.44 ± 2.87 (259, −10–6)	−4.49 ± 2.54 (582, −10–9)	−4.01 ± 2.56 (321, −10–5)	0.02
Satisfaction					
Pre-operative	11.13 ± 6.99 (1452, 0–40)	10.58 ± 7.58 (353, 0–40)	11.02 ± 6.97 (721, 0–40)	11.78 ± 6.40 (378, 0–34)	0.06
30 days	26.68 ± 12.02 (1543, 0–40)	26.46 ± 12.17 (384, 0–40)	26.67 ± 12.15 (770, 0–40)	26.89 ± 11.64 (389, 0–40)	0.88
90 days	31.51 ± 10.19 (1328, 0–40)	31.07 ± 10.81 (310, 0–40)	31.81 ± 9.91 (663, 0–40)	31.34 ± 10.17 (355, 0–40)	0.53
Δ 30 days	15.71 ± 13.41 (1414, −32–40)	16.19 ± 13.84 (344, −26–40)	15.69 ± 13.33 (701, −32–40)	15.29 ± 13.16 (369, −30–40)	0.65
Δ 90 days	20.35 ± 12.13 (1233, −32–40)	20.18 ± 13.07 (283, −26–40)	20.84 ± 11.86 (611, −32–40)	19.62 ± 11.82 (339, −30–40)	0.32
EQ-5D-5L					
Pre-operative	0.479 ± 0.268 (1437, −0.447–1.0)	0.383 ± 0.286 (349, −0.447–0.94)	0.479 ± 0.263 (712, −0.425–1.0)	0.568 ± 0.226 (376, −0.334–0.94)	<0.0001
30 days	0.730 ± 0.174 (1366, −0.249–1.0)	0.694 ± 0.183 (336, −0.07–1.0)	0.739 ± 0.176 (680, −0.249–1.0)	0.747 ± 0.156 (350, 0.067–1.0)	<0.0001
90 days	0.841 ± 0.169 (1254, −0.216–1.0)	0.817 ± 0.165 (286, −0.125–1.0)	0.849 ± 0.166 (631, −0.216–1.0)	0.849 ± 0.177 (337, −0.153–1.0)	0.019
6 months	0.875 ± 0.156 (1225, −0.04–1.0)	0.850 ± 0.174 (292, −0.04–1.0)	0.878 ± 0.149 (603, −0.04–1.0)	0.893 ± 0.149 (330, −0.022–1.0)	0.002
12 months	0.894 ± 0.154 (1081, −0.329–1.0)	0.879 ± 0.171 (261, −0.329–1.0)	0.888 ± 0.152 (519, −0.312–1.0)	0.919 ± 0.134 (301, −0.04–1.0)	0.004
Δ 30 days	0.247 ± 0.279 (1252, −0.719–1.066)	0.313 ± 0.295 (302, −0.47–1.066)	0.254 ± 0.280 (619, −0.719–1.007)	0.175 ± 0.245 (331, −0.614–0.879)	<0.0001
Δ 90 days	0.356 ± 0.277 (1147, −0.769–1.153)	0.424 ± 0.298 (256, −0.438–1.087)	0.363 ± 0.272 (572, −0.63–1.153)	0.289 ± 0.253 (319, −0.769–1.076)	<0.0001
Δ 6 months	0.389 ± 0.272 (1123, −0.424–1.175)	0.455 ± 0.313 (261, −0.353–1.175)	0.391 ± 0.261 (549, −0.40–1.153)	0.329 ± 0.241 (313, −0.424–1.008)	<0.0001
Δ 12 months	0.403 ± 0.271 (999, −0.443–1.153)	0.482 ± 0.308 (239, −0.443–1.087)	0.394 ± 0.262 (474, −0.272–1.153)	0.353 ± 0.238 (286, −0.442–1.064)	<0.0001

Table 5. *Cont.*

	All Activity Levels Mean ± SD (n, Min–Max)	Low Pre-Operative Activity Mean ± SD (n, Min–Max)	Moderate Pre-Operative Activity Mean ± SD (n, Min–Max)	High Pre-Operative Activity Mean ± SD (n, Min–Max)	*p* Value
EQ-VAS					
Pre-operative	72.06 ± 16.75 (1429, 2–100)	69.83 ± 17.57 (350, 10–100)	71.60 ± 17.13 (704, 2–100)	74.98 ± 14.77 (375, 20–100)	0.0001
30 days	79.89 ± 13.44 (1367, 0–100)	77.77 ± 14.99 (336, 0–100)	80.63 ± 12.72 (684, 0–100)	80.51 ± 13.07 (347, 0–100)	0.004
90 days	84.13 ± 11.90 (1245, 0–100)	81.99 ± 13.31 (282, 40–100)	84.44 ± 10.84 (632, 30–100)	85.39 ± 12.35 (331, 0–100)	0.001
6 months	84.95 ± 11.89 (1225, 0–100)	82.53 ± 12.91 (293, 31–100)	84.85 ± 12.27 (603, 0–100)	87.26 ± 9.61 (329, 40–100)	<0.0001
12 months	85.37 ± 12.73 (1083, 0–100)	82.30 ± 14.39 (263, 0–100)	85.84 ± 11.58 (518, 0–100)	87.25 ± 12.65 (302, 0–100)	<0.0001
Δ 30 days	7.86 ± 16.56 (1252, −85–70)	8.54 ± 18.49 (305, −80–68)	8.67 ± 15.81 (620, −71–70)	5.69 ± 15.87 (327, −85–65)	<0.0001
Δ 90 days	12.05 ± 16.20 (1139, −78–88)	12.05 ± 16.34 (256, −45–68)	12.58 ± 16.25 (570, −32–88)	11.09 ± 16.01 (313, −78–55)	0.43
Δ 6 months	12.67 ± 16.9 (1119, −80–88)	13.12 ± 18.99 (265, −41–73)	12.52 ± 16.94 (544, −80–88)	12.54 ± 14.83 (310, −40–59)	0.88
Δ 12 months	13.04 ± 17.49 (1002, −93–86)	12.58 ± 18.56 (244, −50–86)	13.73 ± 17.24 (471, −90–78)	12.29 ± 16.96 (287, −93–60)	0.49

PROMs (EQ-5D-5L and EQ-VAS) measuring general HRQoL also varied between groups based on pre-operative activity levels. Low-activity participants reported the lowest HRQoL on the EQ-5D-5L and EQ-VAS (Table 5). EQ-5D-5L scores continued to vary by groups throughout the post-operative period investigated, where lower activity groups continued to report lower HRQoL. The low-activity group appreciated the largest improvements on EQ-5D-5L at all timepoints from one month through one year following THA, with all pairwise comparisons significant at one month, and both low and moderate groups demonstrating larger improvements than the high-PA group at one year. The general rating of overall health as reported on EQ-VAS varied among groups post-operatively, where the low pre-operative PA group demonstrated lower scores at 30 days through 1 year post-operation, with differences between groups not meeting MCID for this PROM. At 1 month after THA, the low- and medium-PA groups appreciated larger changes in HRQoL on EQ-VAS. However, changes over the remainder of the post-operative period of interest were similar between all groups. Satisfaction with the hip joint was similar pre-operatively and remained similar between groups at each interval investigated (Table 5). Change in satisfaction from baseline did not vary by pre-operative activity levels.

4. Discussion

In this analysis of a large prospective cohort of participants undergoing THA with pre- and post-operative objectively collected physical activity data, large variations in pre-operative activity levels were observed. Dividing participants according to baseline PA habits demonstrated that those with the lowest step counts before surgery recovered and exceeded pre-operative PA by one month, performing more than twice as many steps daily by three months, which plateaued at this time and was maintained through one year post-operation. Those in the middle quartiles of baseline activity also recovered daily step counts within one month post-operation, performing over 1000 additional steps each day at three months, which was also maintained throughout one year post-operation.

Participants whose baseline activity was within the top quartile demonstrated more gradual recovery, not returning to pre-operative levels fully until one year after THA; however, they did continue to perform more steps at every time interval investigated. High-activity participants reported smaller improvements in joint function, pain, and health-related quality of life; however, satisfaction was similar between groups.

Monitoring of recovery following surgery with objective mobility data collected by wearable activity monitors has recently become more common and may serve as a useful adjunct to traditional methods of assessing function after joint replacement. Prior to the popularization of these devices, activity studies often relied upon self-report by patients by way of diaries or recall methods on questionnaires. Perceived improvements in physical activity and function after THA have been reported; however, objective and subjective measures of recovery have often been shown not to strongly correlate with one another [32,33]. Incidental activity may be inadvertently excluded from subjective reports, questionnaires are subject to potential recall bias, and function questionnaires do not adequately capture activity [35,36]. Harada et al. found that THA patients' self-reports of activity on the University of California Los Angeles Activity Scale (UCLA) as well as objectively measured activity both significantly increased post-operatively [27], while others note patients' report of physical activity was significantly larger than their objectively measured activity [24,37]. Patients blinded to the readings of wearables and asked to estimate walked distances demonstrated 69% mean error pre-operatively, and these errors increased to 93% over time [38]. Subjective reports of activity increased in those patients while actual distance walked decreased, and a minority of participants were consistently under- or overestimators. Researchers have hypothesized that participants frequently overestimate the amount of physical activity performed after arthroplasty due to improvements in function and pain, noting that better function does not necessarily translate to increased activity, though perceived pain appears to be linked to perceived PA [39,40]. It was found that objectively measured activity took longer to recover than did perceived functional improvement, as Western Ontario and McMaster Universities Arthritis Index (WOMAC) and the Harris Hip Score (HHS) were significantly improved at 1 month, while the amount of moderate-to-vigorous physical activity (MVPA) did not increase until 3 months following THA [41]. Several studies have reported significant improvements on function questionnaires without corresponding improvements in objective physical activity [10,29,42,43].

Much of the data in the existing literature investigating the amount of physical activity performed by THA patients support our findings. Tudor-Locke suggested that special populations reported 3500–5500 steps per day in adults with chronic illness, where those with osteoarthritis averaged 4086 and OA with arthroplasty 4892 [44]. Harada et al. reported 5092 steps on average prior to intervention [27], while the cohort participating in a study by Moellenbeck and colleagues performed 5465 on average [29], which is similar to our finding of 5151 daily steps. Conflicting results have been suggested regarding changes following THA. Return to pre-operative step counts is generally achieved by six-to-nine weeks [31,33,43], though changes from baseline have varied. Some studies have reported significant increases at six months or one year in low-to-moderately active participants [27,28,45,46], with increases of generally about 1000 additional steps per day, which is similar to our observation in the low- and moderate-activity participants in this study. Others reporting objective measures with activity monitors report no significant change in PA after arthroplasty [10,29,30,47]. Some authors conclude that the majority of arthroplasty patients do not adopt more active lifestyles after surgery [37,48,49].

The varying conclusions of these studies may be due in part to the participants included and the variation in pre-operative PA levels, as evidenced by large standard deviations considering step counts. In the current study, similar results were found over the entire cohort, where pre-operatively all patients performed an average of 5151 $\pm$ 2973 steps, increasing to only 6244 $\pm$ 3634 steps on average at one year after THA. Importantly, while low-activity participants did increase activity, the activity profiles post-operatively do not suggest adoption of active lifestyles. Other studies have noted observations similar to ours, using both subjective and objective measures [25,26]. However, patients in the moderate pre-operative baseline PA group may be considered as a whole to have moved from a sedentary lifestyle as previously defined into a low-activity category [50]. Our findings regarding inactive and active patients are similar to existing data utilizing self-report, where inactive patients appreciated significant increases in PA following THA, and inactive patients demonstrated decreased activity after surgery [25,26]. High-activity patients continue to perform more activity after THA, as baseline step counts have been suggested as a strong predictor of post-operative PA. These data may be helpful in counseling patient expectations, particularly in younger active patients undergoing arthroplasty to maintain active lifestyles.

Return to function cannot be reliably assessed by PROMs alone, and adjunct methods such as objective activity data should be utilized [33]. These assertions are supported by our data; while pre-operative HOOS JR scores varied statistically, with differences of only 2 points, these do not meet defined MCID thresholds (7–18 points) and are not considered clinically meaningful [34]. Similarly, while low-activity participants significantly increased activity after surgery and high-activity participants experienced a decrease in step counts, both reported significant improvements on KOOS JR by one month. While the low-activity group reported the largest improvement, the 3.5-point difference in change from baseline between low and high groups did not meet clinical significance, highlighting previous literature regarding the role of objectively measured activity as a complementary method to assess post-arthroplasty recovery [51–53].

Lower-activity participants reporting higher levels of pain pre-operatively is not unexpected; however, it cannot be extrapolated from our data that high pain was the cause of low activity, particularly as this group enjoyed the largest numerical pain relief but remained essentially sedentary post-operatively. It has been suggested, however, that engaging in moderate activity after arthroplasty with a “take it easy” approach may result in less pain and more consistent recovery [54]. While we did not attempt to correlate the changes in quality of life with changes in PA, it is also interesting to note that those with all groups, including the high baseline activity group, met MCID for the EQ-5D-5L by 1 month post-operation and EQ-VAS by 3 months post-operation [55] despite the apparent differences in activity recovery. It is also of interest to note that the participants in the highest activity quartile did not report lower satisfaction at three months, particularly given that this group had not yet reached their baseline activity while the other groups had exceeded pre-operative levels by this time.

The prospective nature and its relative size are strengths of this study; however, it is subject to limitations. It was not possible to account for or standardize patient counseling of expectations, which may have impacted patients’ approaches to activity following THA. Further, though the multicenter nature of the study may be considered a potential strength, it was not possible to standardize in-hospital or post-operative standard of care protocols. Additionally, we could not account for complications or readmissions, which may have impacted the activity levels of some participants. Our results could also be impacted by the relatively short pre-operative period of evaluation and only one year of follow up data. Further, it is unclear whether recovery of step counts may have continued to progress beyond one year, particularly in the high-activity group. Though changes in PROMs and subjective activity reports have offered no substantial changes beyond one-year post-operation [56], it is unclear whether this is the case for objective activity data. Additionally, we measured only the volume of step counts, rather than investigating the intensity of activity and cannot account for other types of activity that may have been pursued by this population, such as swimming or bicycling. Given this, it is not possible to determine whether patients were able to fully return to all their pre-operative activities or adopted new activities following THA. The amount of recovery as reported in percentage may be interpreted with caution as well, as those with low levels of baseline activity may appreciate small changes that appear larger given the reference point [23], though changes in step counts as presented appear to be clinically meaningful in low- and moderate-activity patients. All included participants were required to own a smartphone for inclusion, such that our results may not be generalizable to the older population, where this technology has not yet been adopted ubiquitously. Patients agreeing to participate in a study of this care management platform may have been more motivated during post-operative recovery than the general population, potentially limiting generalizability to the knee arthroplasty population at-large. Finally, the heterogeneity of methods to collect objective activity data, as well as the variety of methods used to define low, moderate, and high activity in OA and arthroplasty populations, limits the ability to compare our findings to previous reports in the literature.

5. Conclusions

Highly active patients undergoing THA may not fully recover to pre-operative levels within one year of intervention. Though these patients continue to perform higher levels of activity throughout the post-operative period, they may not achieve the same level of benefit with regards to pain reduction or improvement in general quality of life as low- and moderate-activity patients. Conversations regarding post-operative expectations, particularly in younger patients who undergo THA to maintain an active lifestyle, should include information about the likelihood of exceeding pre-operative activity within the first year following surgery.

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