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Feedback From Activity Trackers Improves Daily Step Count After Knee and Hip Arthroplasty: A Randomized Controlled Trial

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ABSTRACT

Background: Commercial wrist-worn activity monitors have the potential to accurately assess activity levels and are being increasingly adopted in the general population. The aim of this study was to determine if feedback from a commercial activity monitor improves activity levels over the first 6 weeks after total hip arthroplasty (THA) or total knee arthroplasty (TKA).

Methods: One hundred sixty-three consecutive subjects undergoing primary TKA or THA were randomized into 2 groups. Subjects received an activity tracker with the step display obscured 2 weeks before surgery and completed patient-reported outcome measures (PROMs). On day 1 after surgery, participants were randomized to either the “feedback (FB) group” or the “no feedback (NFB) group.” The FB group was able to view their daily step count and was given a daily step goal. Participants in the NFB group wore the device with the display obscured for 2 weeks after surgery, after which time they were also able to see their daily step count but did not receive a formal step goal. The mean daily steps at 1, 2, 6 weeks, and 6 months were monitored. At 6 months after surgery, subjects repeated PROMs and daily step count collection.

Results: Of the 163 subjects, 95 underwent THA and 68 underwent TKA. FB subjects had a significantly higher ($P < .03$) mean daily step count by 43% in week 1, 33% in week 2, 21% in week 6, and 17% at 6 months, compared with NFB. The FB subjects were 1.7 times more likely to achieve a mean 7000 steps per day than the NFB subjects at 6 weeks after surgery ($P = .02$). There was no significant difference between the groups in PROMs at 6 months. Ninety percent of FB and 83% of NFB participants reported that they were satisfied with the results of the surgery ($P = .08$). At 6 months after surgery, 70% of subjects had a greater mean daily step count compared with their preoperative level.

Conclusion: Subjects who received feedback from a commercial activity tracker with a daily step goal had significantly higher activity levels after hip and knee arthroplasty over 6 weeks and 6 months, compared with subjects who did not receive feedback in a randomized controlled trial. Commercial activity trackers may be a useful and effective adjunct after arthroplasty.

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Mobility and physical activity are imperative to healthy aging. Evidence supports the positive benefits of regular physical activity with higher activity being associated with reduction in the risk of

chronic disease and premature mortality [1,2]. More recently, associations such as the Committee on Exercise and Cardiac Rehabilitation of the American Heart Association endorse regular physical activity and even classify it as a modifiable risk factor for prevention from cardiovascular diseases and other chronic diseases, including diabetes mellitus, cancer, obesity, hypertension, bone and joint diseases, and depression [3].

After joint arthroplasty, the aim should, therefore, be not only to improve pain and function but also to improve activity. This activity

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should preferably meet the recommended daily activity levels as recommended by the World Health Organization (WHO), US Center for Disease Control, and the National Heart Foundation of Australia [4,5].

Historically, postoperative activity has been monitored using participant-completed subjective questionnaires [6,7]. However, reports in literature have questioned the accuracy and validity of this form of assessment. It has been identified that in self-assessment of physical activity, people tend to overestimate their level of activity by as much as 50% [5]. Verlaan et al [8] reported that up to 62% of the general population met the activity intensity guidelines according to their self-assessment questionnaire, whereas only 9.6% met these same guidelines, when defined from objective physical activity monitoring.

With the recent development of commercial-based accelerometers (activity trackers), the “subjective” error has been decreased, and it has become easier to accurately measure daily activity level. It has also been identified that these activity trackers have a great potential to accurately assess activity level before and after joint arthroplasty [9]. These devices are largely used in the fitness industry as a motivational tool for those wanting to monitor and improve fitness. More importantly, these devices have been shown to be a valid and reliable assessment tool for activity levels in normal participants [10] and participants after cardiac surgery [11].

In this study, we used commercial activity trackers to monitor and encourage higher activity levels in a series of participants before and after total knee arthroplasty (TKA) or total hip arthroplasty (THA).

Table 1

Daily Step Goal Given to Subjects in the Feedback Group.

| Postop Day | Daily Step Goal |
|------------|-----------------|
| Day 1 | No goal |
| Day 2 | 500 |
| Day 3 | 1000 |
| Day 4 | 1500 |
| Days 5–7 | 2000 |
| Week 2 | 3000 |
| Week 3 | 4000 |
| Week 4 | 5000 |
| Week 5 | 6000 |
| Week 6 | 7000 |

Our hypothesis was that subjects who received feedback of step count in the first 2 weeks after surgery would have higher mean daily step count over the first 6 weeks after TKA or THA. We also examined whether this impacted participant satisfaction, participant-reported outcome measures, or 6-month activity level.

Materials and Methods

This was a single-center parallel group randomized controlled study with an equal allocation ratio. Eligible patients were all adults undergoing primary elective hip or knee arthroplasty under the care of one of the investigating surgeons between May 2016 and

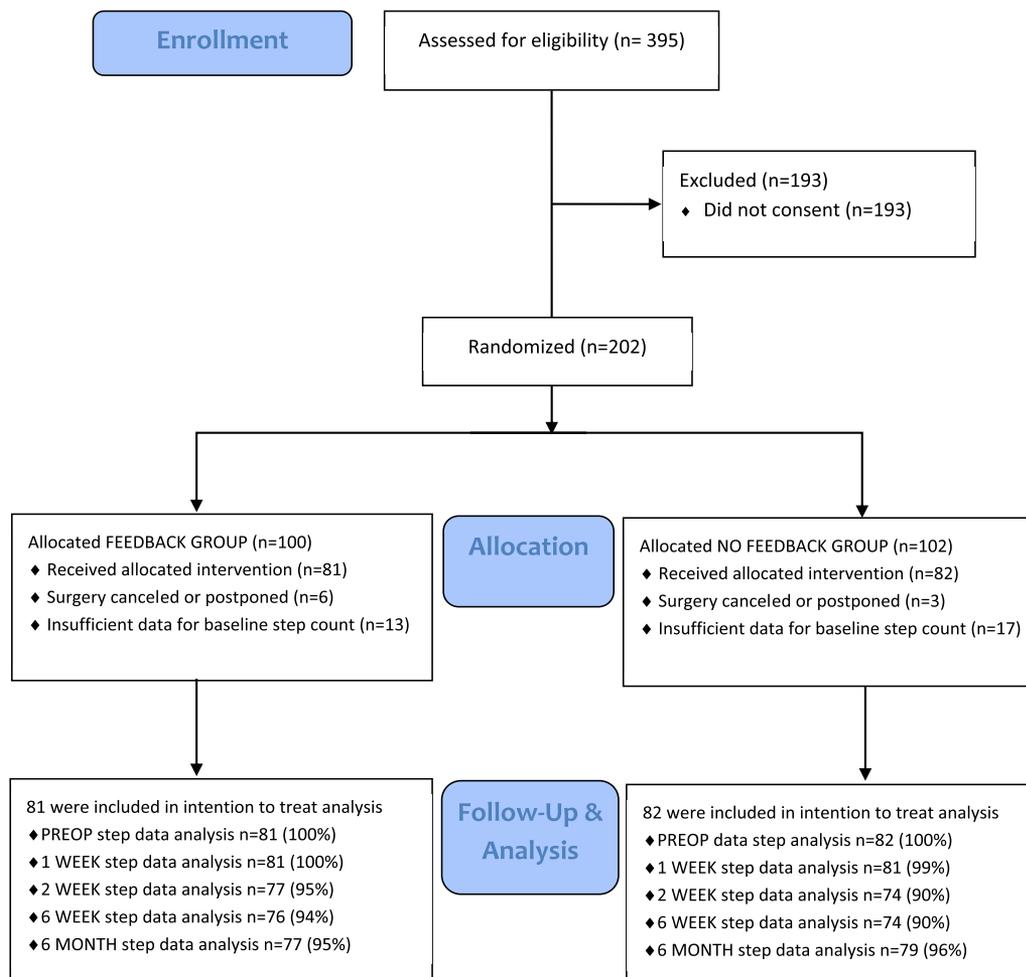


Fig. 1. Participant flowchart according to the CONSORT guidelines.

December 2016. Patients were required to provide written informed consent and were randomized to either control (no feedback [NFB]) group or device feedback (FB) group. Subjects with rheumatoid arthritis or other inflammatory diseases and those undergoing hip arthroplasty after an acute femoral fracture were excluded. Subjects who were not contactable within 2 weeks of their surgery were excluded.

Two weeks before surgery, subjects were contacted via telephone and were invited to participate. All potential participants were informed the purpose of the study. Participants were emailed or posted the written Participant Information and Consent Form as approved by the Hospitals Human Research Ethics Committee. If the participant consented, they received a Garmin Vivofit 2 device for 2 weeks before their surgery. The Garmin Vivofit 2 uses a 3-axis Micro-ElectroMechanical Systems accelerometer to estimate step count. This device has a long battery life of roughly 12 months, and the retail cost is AUD\$109. The device has been shown to be valid and reliable for assessment of step count [12–14].

The display on the Vivofit 2 device, which indicates the number of steps per day, was obscured from all participants in the preoperative period. On day 1 after arthroplasty, randomization was performed. The randomization was blocked in multitudes of 40 with a 1:1 allocation ratio. The random permutation list was generated from <http://www.randomization.com>. From this list, a series of 40 numbered and sealed envelopes were created with the words “Feedback Group” or “No Feedback Group” generated in the order determined by the permutation list. When a participant was to be randomized, the researcher obtained the next sequentially numbered envelope from a contact who was independent of the recruitment process for allocation consignment.

A researcher visited the subject on the first day after surgery and advised as to which group they had been allocated. If the subject was in the “FB group” the cover over the Vivofit display was removed to make the step count visible and he or she was given a daily step goal as indicated in Table 1. Subjects were advised that this goal should be considered a rough guide based on average activity level after arthroplasty and may need to be adjusted in some circumstances for medical or lifestyle reasons. The weekly step goal was selected based on the mean daily steps observed in a previous study of subjects with activity monitors after arthroplasty [15]. The goal of 7000 steps by week 6 was selected, as this is the recommended daily step count for healthy older adults (>65) [16].

Participants in the “NFB group” continued to wear the device with the display obscured for 2 weeks after surgery and were not given a daily step goal.

The mean daily steps from each group for the first 2 weeks was recorded and compared. After 2 weeks, all participants were permitted to remove the cover over the display and see the step count. The nonrandomized group was not given the login or password required to sync the device and therefore could not access their data until after they were unblinded. All participants from both groups continued to wear their device until 6 weeks after surgery. Where possible, the Garmin Vivofit 2 device was synced to the subject's mobile device (phone or tablet) using the Garmin Connect mobile application. If the subject did not have a suitable mobile device, arrangements were made for the device to be synced at least every 3 weeks with the research unit's computers, either in person or via post. At 6 weeks after surgery, participants returned the Garmin Vivofit 2 in person or via post. At 6 months after surgery, subjects wore the Garmin Vivofit 2 again for a period of 3 weeks.

All subjects completed patient-reported outcome measures (PROMs) preoperatively and at 6 months after surgery. The questionnaire included the disease-specific measure of the Knee Injury and Osteoarthritis Outcome Score or Hip Disability and

Osteoarthritis Outcome Score, and the general measure of the EuroQoL-5D: an instrument for measuring quality of life. At 6 months, patients also completed the satisfaction component of the Knee Society Score and graded their satisfaction with their outcome of surgery on a 5-point scale from very satisfied to very disappointed. They were also asked if they would have the same surgery again under the same circumstances (yes/no/unsure).

The study was performed at the Mater Hospital, a private hospital located in Sydney, Australia, where over 2000 arthroplasty procedures are performed annually. The routine care of subjects undergoing arthroplasty included admission on the day of surgery, 5-day postoperative stay in acute care orthopedic ward, commencement of mobilization on day 1 after surgery, and twice-daily physiotherapy sessions for 5 days. The vast majority of subjects then attend inpatient rehabilitation for a further 7–10 days and outpatient sessions twice a week until 6 weeks from surgery.

The study was initially designed to recruit 300 participants. Before the commencement of the study, a series of 30 participants undergoing TKA wore a Garmin Activity monitor for 6 weeks after surgery. In this population, the mean number of recorded steps per day was 6700 (standard deviation 3200) before surgery and 5700 at 6 weeks (standard deviation 2600). These data were used to determine the study sample size for the randomised controlled trial design. Power calculations (from <http://www.statisticalsolutions.net/>) determined that to detect a 25% variation in mean step count, with a power of 0.8 and a significance level of 0.05, 113 participants were required for each group. By oversampling an additional 37 participants in each group, we account for potential withdrawals and loss to follow-up. A single planned interim analysis of the primary outcome measures was performed 7 months after commencement of the study, after recruitment of over 200 subjects. A statistically significant difference between the FB and NFB groups was evident on all primary outcome measures of 1-, 2-, and 6-week step count; therefore, recruitment was ceased after the enrollment of 202 subjects.

Table 2

Baseline Demographic and Clinical Characteristics of the Feedback and No Feedback Groups.

| Demographic and Baseline Clinical Characteristics | Feedback Group (N = 81) | No Feedback Group (N = 82) | P |
|---|-------------------------|----------------------------|------|
| Op type | | | |
| THA | 52 (64%) | 43 (53%) | .128 |
| TKA | 29 (36%) | 39 (48%) | |
| Gender | | | |
| Male | 45 (56%) | 36 (44%) | .137 |
| Side | | | |
| Right | 48 (59%) | 53 (65%) | .480 |
| Age | 67 (9) | 66 (9) | .289 |
| BMI | 27.8 (4.5) | 28.2 (4.1) | .951 |
| Preop mean daily step count | 6953 | 7655 | .146 |
| Preop patient-reported scores | | | |
| KOOS | | | |
| Symptoms | 45 (18) | 45 (18) | .849 |
| Pain | 47 (16) | 45 (19) | .443 |
| Function | 50 (18) | 51 (21) | .794 |
| QoL | 30 (19) | 33 (18) | .335 |
| EQ-5D | | | |
| Mobility | 2.8 (0.9) | 2.7 (0.9) | .461 |
| Self-care | 1.5 (0.8) | 1.4 (0.8) | .426 |
| Usual activities | 2.6 (1.0) | 2.4 (0.9) | .201 |
| Pain | 3.2 (0.9) | 3.3 (0.6) | .591 |
| Anxiety/depression | 1.6 (0.9) | 1.6 (0.8) | .677 |
| General health | 71 (18) | 72 (16) | .786 |

Data are expressed as means (standard deviation) or numbers (%).

BMI, body mass index; KOOS, Knee Injury and Osteoarthritis Outcome Score; THA, total hip arthroplasty; TKA, total knee arthroplasty; QoL, Quality of Life.

Table 3
Mean Daily Step Count Expressed as Percentage of Preoperative Step Count for the Feedback and No Feedback Groups.

| Mean Daily Step Count | Feedback Group (N = 81) (%) | No Feedback Group (N = 82) (%) | P Value | Ratio | Mean Difference (%) | 95% CI for the Mean Difference (%) | Cohen's d |
|-----------------------|-----------------------------|--------------------------------|---------|-------|---------------------|------------------------------------|-----------|
| 1 wk | 20 | 14 | .002 | 1.43 | 6 | 2-10 | 0.5 |
| 2 wk | 44 | 33 | .001 | 1.33 | 11 | 5-18 | 0.5 |
| 6 wk | 103 | 85 | .005 | 1.21 | 18 | 6-31 | 0.5 |
| 6 mo | 137 | 117 | .030 | 1.17 | 20 | 2-38 | 0.4 |

CI, confidence interval.

Statistical Methods

The primary end point of the study was the average daily step count as measured using the Garmin Vivofit device at 1 week, 2 weeks, and 6 weeks after surgery. This was expressed as a percentage of the subject's preoperative step count. Secondary end points were 6-month PROMs and mean daily step count. Continuous variables such as mean step count and patient-reported scores were compared between treatment groups with independent *t* tests. Changes over time were assessed using paired *t* tests. The magnitude of mean differences between treatment groups were assessed with Cohen's *d*. Difference in proportions of patients between treatment groups were assessed using the chi-square test (χ^2 test). Fisher's exact test was used for comparing proportions when the cell counts were less than 5. Risk ratios and 95% confidence intervals were calculated for proportions as a risk estimate.

Results

Between May 2016 and December 2016, 395 subjects underwent primary hip or knee arthroplasty under the care of the investigating surgeons. Participant flowchart is shown according to the Consolidated Standards of Reporting Trials (CONSORT) guidelines in Figure 1. Two hundred two subjects met the eligibility criteria and were enrolled in the study; 9 patients were excluded as their surgery was canceled or postponed and 30 patients were excluded as there were insufficient data for baseline step count. The final groups included 81 subjects in the FB group and 82 subjects in the NFB group.

Baseline demographic and clinical characteristics of the 2 groups are shown in Table 2. There were no significant differences between the FB and NFB groups for any of the baseline variables or characteristics. Daily step count was recorded for each subject as a mean of 36 of a possible 42 days in the first 6 weeks after surgery. Days missing step counts was either due to noncompliance with wearing the device or difficulties in successfully syncing the device to retrieve step counts.

Mean daily step count for the 2 groups at 1 week, 2 weeks, 6 weeks, and 6 months is shown in Table 3 and Figure 2. The FB group had a significantly higher mean step count at all review points than the NFB group. Cohen's *d* was 0.4-0.5, indicating a moderate effect size [17]. The mean difference between groups ranged from 6% to 20% between 1 week and 6 months after surgery. For the FB group, the mean daily step count increased from 7069 preoperatively to 8326 at 6 months after surgery ($P = .001$). For the NFB group, the mean daily step count increased from 7748 preoperatively to 8467 at 6 months after surgery ($P = .001$).

Seven thousand steps per day is recommended as a suitable activity level for subjects over 65 years [16]. The proportion of subjects achieving a mean of 7000 or more steps each day is shown in Figure 3. Subjects in the FB group were 1.7 (95% confidence interval 1.2-2.6) more likely to be achieve a mean 7000 steps per day than subjects in the NFB group at 6 weeks after surgery ($P = .02$).

The patient-reported outcome scores reported at 6 months for the 2 groups are shown in Table 4. There was no significant

difference between the 2 groups for patient-reported outcome scores at 6 months after surgery.

Patient satisfaction with the outcome was assessed at 6 months, and the results are shown in Table 5. There was a trend ($P = .089$) toward higher proportion of satisfied or very satisfied subjects in the FB group, compared with the NFB group.

Thirty-day readmission was monitored for all subjects. One patient in the FB group was readmitted with a postoperative wound dehiscence at 17 days postoperatively and underwent debridement of the surgical wound and administration of intravenous antibiotics for 5 days. Tissue culture returned positive for *Staphylococcus epidermidis*. No further treatment was necessary. One patient in the NFB group was readmitted after 28 days for investigation of pyrexia of unknown origin. No treatment was required.

Discussion

Subjects who received feedback from a commercial activity tracker with a daily step goal had significantly higher activity levels after hip and knee arthroplasty at all measured time points over 6 months, compared with subjects who did not receive feedback. Feedback from activity trackers was found to be an effective tool for increasing early mobilization, with subjects being motivated to "achieve their daily goal".

This study is the first to report the positive effect of the use of activity monitors after knee and hip arthroplasty. Our results indicated that in the FB group, the patients receiving a daily goal and daily feedback in the first 2 weeks after surgery led to increased activity in the acute phase, increased activity at 6 months, and a trend to improved higher patient satisfaction at 6 months ($P = .09$). The FB group had significantly higher activity than the NFB group by 45% at 1 week, 34% at 2 weeks, 26% at 6 weeks, and then finally 17% at 6-month mark. With the evident benefits of physical activity to healthy aging, especially after surgery, this increased activity can be considered a positive effect for a successful surgery.

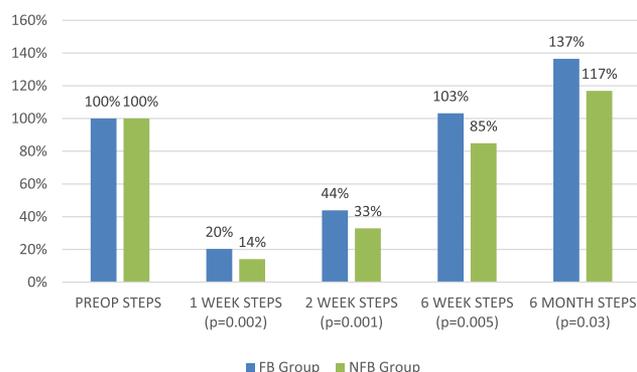


Fig. 2. Mean step count as a percentage of preoperative steps in the feedback and no feedback groups over time.

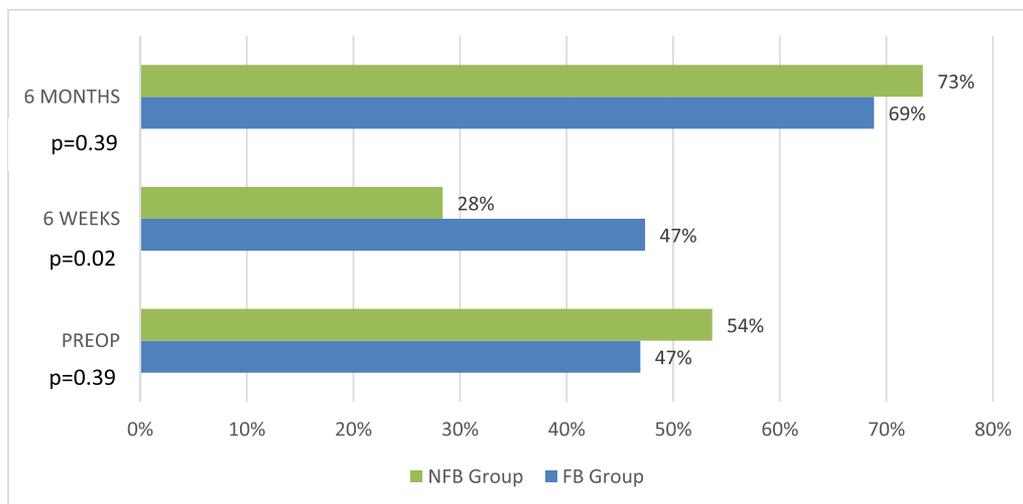


Fig. 3. Proportion of subjects in the feedback and no feedback groups taking a mean 7000 or more steps each day over time.

The success after joint arthroplasty can be measured by a variety of parameters. It is important to aim to improve not only pain and function but also physical activity. Physical activity includes an improvement in mobility which can be measured by daily step count. However, until now, a reliable objective measure of improved step count after arthroplasty has not been reported. The WHO, US Center for Disease Control, and the National Heart Foundation of Australia have released a list of recommendations of daily activity or step count to improve an individuals' health and reduce the risk of disease. According to their recommendations, an average individual needs to take 10,000 steps a day to improve their health and reduce the risk of disease [18–20]. It is further specified that the recommended daily step count for healthy older adults (>65 years) is 7000–10,000 [21]. The proportion of subjects taking 7000 steps or more increased from 50% before surgery to 70% at 6 months after surgery. The mean daily step count at 6 months was increased compared with preoperative status in 66% of the subjects. Even though a value of 10,000 steps/day currently is promoted as a target for obtaining health benefits, the increase seen in these patients after arthroplasty can be seen as a step in the right direction toward improving their health outcomes.

It should be noted that the groups were differentiated by the presence or absence of feedback from the activity monitor only for

the first 2 weeks after surgery. After this time, both groups were able to see their daily step count on the device, but only the FB group was encouraged to use the weekly step goals (see Table 1). It is interesting that the early feedback from the device and the use of a goal had a positive effect over the full 6 months of the study. We hypothesize that the early feedback was a powerful and persisting motivator for subjects to be aware of their activity level over the long term.

With the recent rise in technological based assessment tools, it is important for the orthopedic fraternity to stay up to date [22]. According to the WHO, physical activity should be assessed by its 4 components: frequency, intensity, time, and the type of activity. Modern commercially available activity trackers have the ability to monitor all the frequency, intensity, time, and the type of activity components. Physical performance is used as an assessment tool for patient recovery, rehabilitation, and clinical progress post-operatively. It is, therefore, important to be able to measure this accurately. The devices used in this study did not include a heart rate monitor to assess intensity, rather we deliberately focused on the daily step count, as it is our opinion that in the older population group, simpler goals may just be more appropriate. There are different forms of activity monitors with increasing levels of complexity and accuracy but ultimately just a basic, accurate activity monitor proved to be valuable in the rehabilitation of the patients who underwent joint arthroplasty.

Patient satisfaction is the ultimate indicator of successful surgery. At 6 months after surgery, 91% of subjects in the FB group reported that they were satisfied or very satisfied with the outcome of the surgery, compared with 83% of the subjects in the NFB group ($P = .089$). While this trend is encouraging, it was not reflected in the other patient-reported outcomes at 6 months, with no significant difference observed between the groups for the disease-specific Knee Injury and Osteoarthritis Outcome Score/Hip disability and Osteoarthritis Outcome Score subscores ($P > .65$) or the EuroQol-5D general health measure ($P > .17$).

In 2001, a group of surgeons from Europe coined the term “ERAS” (enhanced recovery after surgery). Their research has highlighted the focus on the quality of postoperative recovery and rested on several factors: a multimodal team approach, preoperative counseling, standardized analgesic and anesthetic protocols, optimization of nutrition, and early mobilization. Paying attention to these elements they stated: “enhanced recovery after surgery practices improve the opportunity for rapid, uncomplicated

Table 4
Patient-Reported Outcome Scores for the 2 Groups at 6 Mo.

| Patient-Reported Scores | Feedback Group (N = 80) | No Feedback Group (N = 82) | P |
|-------------------------|----------------------------|-------------------------------|------|
| COOS, mean (SD) | | | |
| Symptoms/100 | 75.6 (21.2) | 75.1 (19.2) | .886 |
| Pain/100 | 86.0 (13.8) | 85.4 (15.3) | .801 |
| Function/100 | 87.3 (10.2) | 86.4 (13.7) | .651 |
| QoL/100 | 75.5 (17.2) | 74.8 (20.0) | .812 |
| EQ-5D, mean (SD) | | | |
| Mobility/5 | 1.5 (0.8) | 1.3 (0.7) | .176 |
| Self-care/5 | 1.1 (0.6) | 1.1 (0.3) | .434 |
| Usual activities/5 | 1.5 (0.8) | 1.4 (0.6) | .435 |
| Pain/5 | 1.7 (0.8) | 1.8 (0.7) | .836 |
| Anxiety/depression/5 | 1.2 (0.6) | 1.3 (0.6) | .529 |
| General health/10 | 7.8 (1.9) | 8.2 (1.6) | .160 |

EQ-5D, EuroQol-5; KOOS, Knee Injury and Osteoarthritis Outcome Score; SD, standard deviation.

Table 5
Patient-Reported Satisfaction for the 2 Groups at 6 mo.

| Satisfaction at 6 mo | Feedback Group (N = 80) | No Feedback Group (N = 82) | P | Risk Ratio | 95% CI |
|--|-------------------------|----------------------------|------|------------|---------|
| Satisfied or very satisfied, N (%) | 73 (91%) | 68 (83%) | .089 | 1.10 | 1.0–1.2 |
| Same surgery again, N (%) | 78 (98%) | 77 (94%) | .230 | 1.04 | 1.0–1.1 |
| Knee society satisfaction score, mean/40 | 34.1 | 33.6 | .691 | | |
| Knee society expectation, score/15 | 10.4 (3.3) | 9.9 (2.9) | .308 | | |

CI, confidence interval.

recovery after surgery with both short- and long-term benefits for patients while improving quality and saving money” [23] With the focus on early mobilization in joint arthroplasty, it has historically been difficult to monitor postoperative mobility with an objective scoring system or scale that accurately identified the patients level of activity. We believe the use of activity monitors can potentially lead to improved monitoring and ultimately improved activity outcomes. Activity monitors have been enthusiastically adopted by the younger populations. A recent commercial consumer reports of 1000 respondents suggest that over 50% of 18- to 64-year-olds own at least one wearable device and report health as the primary motivation for purchase [24]. It is likely that this technology will be used with increasing frequency in the arthroplasty population of the future.

Subjects in this study stayed in acute care hospital for a mean of 5 days after arthroplasty. The most common practice was that they then attended inpatient rehabilitation for a further week. This practice is considerably slower than the usual care after arthroplasty seen in majority of other centers. This limits the generalizability of our findings. However, it is plausible that the benefit of receiving feedback from an activity monitor is relevant to populations of both slow stream and fast stream rehabilitated protocols.

We identified some limitations to our study. We question the accuracy of these activity trackers at low speeds. The devices make an estimate of daily step count using a combination of motion sensors, including an accelerometer, which then use an algorithm to estimate step count. It is the algorithm that allows the device to differentiate between simple movements of the arm and walking. It can be expected that the algorithms are based on “normal” walking speeds and so lack the sensitivity to accurately measure very slow speed walking or movement patterns that are complicated by use of walking aids, such as crutches or walking frames. This is especially a concern in the first days after surgery when activity levels are expected to be at a slower rate [25–27]. This potential error would affect both groups in this study equally, so should not have unevenly biased our early results. Regardless, we advocate that these devices are probably better used after the first week from surgery when walking patterns are starting to normalize. In addition, we lost a number of patients during our follow-up either due to failure of device or information loss. We contributed this to possible hardware or user failure. Overall, the activity monitors were well tolerated by subjects but for some elderly patients, there were challenges with successfully managing the technology. Certainly, setting up the devices correctly required some form of assistance in a significant proportion of these subjects. This is likely to become less of an issue over time as the younger populations are vastly more familiar and comfortable with using modern technologies. Finally, during our exclusion process, 30 patients had to be excluded due to late arrival or delivery of their devices (more than 1-week postop). Despite these difficulties, we achieved a more than 90% of successful data retrieval of the study cohort and remained suitably powered for detecting differences in step counts between the groups.

Conclusion

In a randomized controlled trial, subjects who received feedback from a commercial activity tracker with a daily step goal had significantly higher activity levels after hip and knee arthroplasty over 6 months, compared with those who did not receive feedback. Commercial, noninvasive, light-weight, low-cost accelerometers may be a useful and effective adjunct to treatment after arthroplasty.

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