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The role of commercially available smartphone apps and wearable devices in monitoring patients after total knee arthroplasty: a systematic review

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- *Purpose:* Commercially available smartphone apps and wearable devices have proven valuable in a variety of clinical settings, yet their utility in measuring physical activity and monitoring patient status following total knee arthroplasty (TKA) remains unclear.
- *Methods:* A systematic review was performed to assess the evidence supporting the use of smartphone apps and wearable devices to assist rehabilitation interventions following TKA. A search was conducted in the PubMed, Cochrane, Medline, and Web of Science databases in September 2021.
- *Results:* One hundred and seventy-six studies were retrieved, of which 15 met inclusion criteria, including 6 randomized control trials. Four of these studies utilized smartphone apps, seven utilized wearable devices, and four utilized a combination of both. A total of 1607 TKA patients participated in the included studies. For primary outcomes, three reported on device accuracy, three on recovery prediction, two on functional recovery, two on physical activity promotion, two on patient compliance, two on pain control, and one on healthcare utilization.
- *Conclusion:* Commercially available smartphone apps and wearable devices were shown to capably monitor physical activity and improve patient engagement following TKA, making them potentially viable adjuncts or replacements to traditional rehabilitation programs. Components of interventions such as step goals, app-based patient engagement platforms, and patient-specific benchmarks for recovery may improve effectiveness. However, future research should focus on the economics of implementation, long-term outcomes, and optimization of compliance and accuracy when using these devices.

Keywords

- total knee arthroplasty
- TKA
- wearable devices
- smartphone apps
- knee rehabilitation
- patient monitoring

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Introduction

Total knee arthroplasty (TKA) is a highly successful surgery associated with considerable medium- and long-term benefits for patients (1). The demand for TKA surgery is rising in the United States and will create corresponding increases in healthcare costs and workforce burden (2). Post-acute care costs of lower limb arthroplasty account for 36% of the total episode of care costs (3). Limiting these costs while improving patient outcomes has become a central focus of research in TKA.

Meanwhile, the growing popularity of commercially available wearable devices and smartphones apps offers a novel way to remotely monitor patients and objectively measure their recovery. These devices can gather a wide variety of physical activity data and create platforms for patients to monitor their performance, receive key health information, and connect with clinicians. Currently, most postoperative rehabilitation from TKA occurs in the outpatient setting or at home. This leads clinicians to rely on reports from outpatient physical therapy or subjective methods such as patient-reported outcomes measures (PROMs) to measure recovery (4). However, previous studies have outlined concerns over the standardization of PROMs as the only measure of recovery (5, 6). Moreover, clinic visits to evaluate recovery have often been reduced to 4–6 weeks postoperatively, increasing the possibility for important landmarks of recovery to be missed. This raises the potential value of objective activity measurement and the consistent contact between patients and surgical

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teams that smartphone apps and wearable devices offer following TKA.

The use of wearable devices and smartphone apps to measure physical activity and aid health interventions has been widely reported in other settings (7, 8, 9, 10, 11). Other fields, such as spinal surgery, have utilized this technology to monitor patient recovery kinetics following surgery (12, 13). However, many studies have questioned their use following lower limb surgery. Two systematic reviews found that the current smartphone apps available for TKA and total hip replacement (THA) have significant variability in their quality and overall poor readability for patients (14, 15). Additional reviews have found limited evidence for the long-term efficacy of these devices and a lack of standardization in their use following joint replacement (16, 17). Of key concern is the accuracy of these technology when measuring physical performance such as step count, range of motion, and gait kinematics.

Despite the existing literature measuring the clinical value of this technology, more research is needed to delineate their use in the context of TKA. In the context of this procedure, different technologies should be analyzed for advantages in device accuracy and patient compliance as well as the impact on functional recovery, physical activity promotion, pain control, goal setting, and healthcare utilization. To date, there has been no systematic review of studies measuring the impact of this technology on TKA rehabilitation. The aim of this review is to systematically identify all studies which used commercially available smartphone apps or wearable activity monitors to measure physical activity and monitor patient status following TKA.

Materials and methods

This review is reported according to the 2020 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement. It was also registered in the PROSPERO registry. There was no funding associated with this review.

A computer-based systematic search was completed in September 2021 of the PubMed, Cochrane Library, MedLine, and Web of Science databases. Articles published in the English language from January 2000 to September 2021 were included. Search strategy terms for smartphone apps were as follows: ((‘Arthroplasty, Replacement, Knee’[Mesh]) OR ‘Knee Prosthesis’[Mesh] OR ‘knee replacement’) AND (‘smartphone application’ or ‘mobile application’ OR app). Search strategy terms for wearable devices were as follows: ((‘Arthroplasty, Replacement, Knee’[Mesh]) OR ‘Knee Prosthesis’[Mesh] OR knee replacement) AND (Fitbit OR Garmin OR Apple OR Misfit OR Polar OR Samsung Gear OR TomTom OR Lumo) AND (tracker OR device OR wearable OR sensor OR technology). The most popular wearable activity brands preidentified in the literature (Fitbit, Garmin, Apple, Misfit, Polar, Samsung Gear, TomTom, and Lumo) were included in the search strategy for wearable devices (18). Inclusion criteria were commercially available wearable technology or smartphone apps capable of monitoring physical activity and patient status after total knee replacement. Exclusion criteria included non-wearable technology, not commercially available devices or apps, pediatric patients, preoperative-only interventions, ongoing studies, and non-clinical studies such as editorials. Only commercially available technology was included in this review due to their greater accessibility and familiarity in the patient population. Additional studies that did not meet the original search criteria were added based on independent expertise by senior author VH.

Once the systematic search was completed and after the removal of duplicates, two independent reviewers then screened studies for relevance by title and abstract. The remaining studies were then screened by both independent reviewers on inclusion and exclusion criteria. Any differences in reviews were verbally sorted and resolved by consensus. One author extracted data from each full-text study included in the final analysis into standardized tables found in Tables 1, 2, and 3. Data extracted included country of study, name of device or app used, app or device function, the aim of the study, study design, the total number of TKA patients, primary outcomes, and analysis. Covidence online software was used to facilitate citation tracking, screening of abstracts and full-text articles, and extraction of data.

The Cochrane Risk of Bias in Randomized Trials (RoB 2.0) and Risk of Bias in Non-Randomized Studies of Interventions (ROBINS-I) tools were used to assess for risk of bias in randomized control trials (RCTs) and observational studies, respectively (19, 20). RoB 2.0 judges bias as low risk, some concerns, or high risk across five domains (randomization, deviation from intended intervention, missing outcomes, measurement of outcomes, and selection of the reported result). ROBINS-I categorizes risk as low risk, moderate risk, serious risk, or critical risk across seven domains (confounding, selection of participants, classification of intervention, deviation from intended intervention, missing data, measurement of outcomes, and selection of the reported result).

Results

Of a total of 60 full-text studies screened by inclusion and exclusion criteria, 15 studies were identified (Fig. 1). Four studies utilized smartphone apps (Table 1), seven studies utilized wearable devices (Table 2), and four studies utilized a combination of both (Table 3) to monitor physical activity and patient status after TKA. In all, 1607

Table 1 Smartphone apps.

Reference	Smartphone app	App function	Study design	Study population	Aim of study	Primary outcome	Results and conclusions
Castle *et al.* (37)	Dr. Goniometer	Photo-based goniometer	Diagnostic test accuracy study	27 TKA patients	Determine reliability and validity of the app to remotely assess knee ROM in a TKA patient population	Device accuracy	The DrG app and a goniometer had strong correlations for flexion ($r = 0.94$) and extension ($r = 0.90$). The DrG app offers an accurate and practical way to remotely monitor knee ROM following TKA.
Pronk *et al.* (29)	PainCoach	Provides advice on medication use, exercise and when to call the clinic in response to patient input of pain experience.	Randomized control trial	71 TKA patients	Investigate effects of app on pain control and opiate use in first 2 weeks at home following TKA	Pain control	PainCoach group used 23.2% less opiates ($P = 0.02$). With active use of the app, there was a 4.1 times faster reduction of the VAS pain score during activity ($P = 0.02$) and 6.3 times faster reduction at night ($P = 0.001$).
Timmers *et al.* (31)	Patient Journey	A personal code unlocks day-to-day postoperative information and push notifications on topics such as pain and physiotherapy as well as allows patients to log pain scores and upload photos of wounds.	Randomized control trial	213 TKA patients	Determine if active education with timely, day-to-day postoperative care information through an app can lead to decreased level of pain compared to those who receive standard information from the app.	Pain control	Compared to standard patient education, use of an app with timely and active education resulted in statically ($P < 0.05$) significant decreases in all levels of pain and improvements in physical functioning, quality of life, and ability to perform physiotherapy exercises in the 4 weeks following TKA.
Lyman *et al.* (30)	The Moves	Uses the smartphone's accelerometer to count daily steps and provides a web link to complete patient-recorded outcome measures (PROMs). The app is no longer available as of 2018.	Observational	139 TKA and 128 THA patients	Test smartphones' ability to passively collect daily step data and PROMs to track recovery after joint replacement.	Patient compliance	68% of TKA patients completed at least 6 months of follow-up. Step data were available for 92% of days from male patients and 86% of days from female patients. Completion rates were satisfactory, supporting the use of smartphone technology in assessing post-TKA patients. An inability to ensure patients always carry their phones, privacy concerns and difficulty aggregating data limited analysis.

TKA patients participated in the included studies. The mean age of all TKA participants was 64.5 years old and 40.7% of participants were male.

Smartphone apps

Among the four studies that utilized smartphone apps, 450 TKA patients were included. Mean age of all TKA participants was 64.1 years old and 42.7% of all participants were male. BMI data was not provided in all studies. This included two RCTs and two observational studies. Primary outcomes included knee pain control in two studies, patient compliance in one study, and device accuracy in one study.

Wearable devices

In the seven studies that utilized wearable devices, 389 TKA patients were included. Participants had a mean age of 66.1 years old. The percentage of male participants was 37.1%. Patient BMI data were not provided by all studies. Two of the included studies were RCTs, while the other five were observational studies. Primary outcomes included recovery prediction in three studies and physical activity promotion, device accuracy, patient compliance, and healthcare utilization in one study, each.

Combined smartphone app and wearable device interventions

Four studies utilized a combination of smartphone apps and wearable devices. These studies included a total of 768 TKA patients. Participants had a mean age of 64.0 years old. The mean BMI of all participants was 31.4 and 41.4% of participants were male. Of the included studies, two were RCTs and two were observational studies. Primary outcomes included functional recovery in two studies, physical activity promotion in one study, and device accuracy in one study.

Risk of bias in individual studies

The results of the risk of bias assessments for each study are presented in Table 4. All six RCTs included in this study were analyzed using the Cochrane Risk of Bias 2.0 tool and found to have some concern for bias in at least one domain. The nine observational or non-randomized quasi-experimental studies were analyzed using the ROBINS-I tool. One of those studies was found to be at low risk of bias across all domains, seven were found to be at low or moderate risk of bias for all domains, and one study was found to be at serious risk of bias in at least one domain. No RCT was found to be at critical risk of bias, and no observational study was found to be at high risk of bias in any domain. Blinding of participants and outcome assessors were consistently found to show concern for bias in the RCTs. Among the observational studies, the

Table 2 Wearable devices.

Reference	Wearable device	Device function	Study design	Study population	Aim of study	Primary outcome	Results and conclusions
Van der Walt *et al.* (27)	Garmin Vivofit 2	Measures step count using an accelerometer	Randomized control trial	68 TKA patients and 95 THA patients	Determine if step count feedback from a commercial activity monitor improves activity over the first 6 weeks following TJA.	Physical activity promotion	Patients receiving feedback had a significantly higher ($P < 0.03$) mean daily step count by 43% in week 1, 33% in week 2, 21% in week 6, and 17% at 6 months. Commercial activity trackers with step count feedback are associated with higher activity levels after TJA and may be a useful adjunct after surgery.
Kelly et al. (35)	Fitbit Zip	Measures step count using an accelerometer	Observational	62 TKA patients	Understand the impact of applying five different compliance criteria on physical activity tacking data of TKA patients as well as investigate causes of variation in compliance outcomes.	Patient compliance	There was an average 24% difference in reported patient compliance between the most lenient and strictest criteria. Older age was associated with decreased compliance in the first 2 weeks after surgery ($P = 0.04$). The use of lenient compliance criteria, such as >0 steps, and wearing of devices on the wrist can avoid unnecessary data exclusion and improve data quality.
Vaughn et al. (39)	Fitbit Zip	Measures step count using an accelerometer	Observational	28 TKA and 23 THA patients	Determine if patients accurately report distance walked compared to that measured by an accelerometer within a 50% margin of error.	Device accuracy	The mean error of reporting was >50% both preoperatively ($P = 0.002$) and postoperatively ($P < 0.001$). The mean magnitude of error was 69% preoperatively and 93% postoperatively. Providers should exercise caution when interpreting patient reported activity levels before and after TKA.
Twiggs et al. (32)	Fitbit Flex	Measures step count using an accelerometer	Observational	94 TKA patients	Determine benchmarks for expected post-operative activity using activity data from osteoarthritis patients undergoing TKA.	Recovery prediction	Significant correlations of preoperative step count, BMI, and Short Form 12 Physical Component Summaries (SF-12) were found with 6 week postoperative step count. These measures could be used to determine patient-specific benchmarks to monitor expected recovery.
Bini et al (34)	Fitbit Flex, Mio Activity Tracker, and Lumo Run	Quantitative data (Fitbit, Mio) on steps, distance, and activity. Qualitative data (Lumo) on cadence, bounce, and rotation.	Observational	9 TKA patients and 13 THA patients	Demonstrate the feasibility of utilizing wearable sensors coupled with machine learning (ML) to predict downstream outcomes of TJA in the early postoperative period.	Recovery prediction	ML algorithms were used to create predictive models that utilized sensor data from as early as 11 days postoperatively to successfully cluster patients into groups which correlated to 6-week PROMs. Thus, artificial intelligence with data from activity sensors in the perioperative period can be used to predict clinical outcomes.
Patterson et al (33)	Fitbit Flex	Measures data on steps, distance, floors climbed, calories expanded, and active minutes.	Observational	8 TKA and 12 THA patients	Determine if a consumer-wearable sensor can stratify patients by change in activity before and after TJA to identify slower-recovering patients.	Recovery prediction	All patients met minimal clinical benefit thresholds of TJA within 6 weeks. Decreased postoperative activity was associated with greater pain reduction ($P = 0.03$). Remote analysis of outpatient wearable sensor data may permit detection of early problems after TJA.
Mehta et al. (28)	Withings	Hybrid smartwatch measures physical activity such as step count	Randomized Control Trial	182 TKA patients and 80 THA patients	Evaluate the effect of activity monitoring and bi-directional text messaging on rate of discharge to home and other clinical outcomes after TJA.	Healthcare utilization	There was no significant difference in the rate of discharge to home between the usual care arm (95% CI, 48.5–65.9%) and the intervention arm (95% CI, 47.9–65.7%). There was a significant reduction in rehospitalization rate in the intervention arm ($P = 0.01$), which may have resulted from goal setting and connection to the care team.

Table 3 Combined smartphone apps and wearable device studies.

Reference	App and device	App and device function	Study design	Study population	Aim of study	Primary outcome	Results and conclusions
Crawford *et al.* (24)	Apple Watch and mymobility smartphone-based care platform	Consists of a patient app on both the iPhone and Apple Watch and portal for clinicians that allows them to view patient engagement, activity levels, PROMs, and messages.	Randomized control trial	452 TKA patients	Determine the non-inferiority of smartphone-based exercise educational care management after TKA vs traditional in-person physiotherapy.	Functional recovery	There was no significant difference in 90-day mean flexion, 90-day mean single leg stance time, 90-day mean timed up and go time, postoperative urgent care visits, or 90-day readmissions between the two groups. This platform demonstrated non-inferiority to traditional care models and potential to decrease postoperative costs while improving patient engagement and communication with providers.
Tripuraneni *et al.* (25)	Apple Watch and mymobility smartphone-based care platform	Web-based interface that reports data points has a messaging option and sends patients daily reminders on their Apple Watch to complete PROMs and PT routines.	Randomized control trial	337 TKA patients	Determine if the use of a smartwatch paired with a mobile application self-directed (SDR) rehabilitation program rather than formal physical therapy impacted post-operative outcomes after TKA.	Functional recovery	No clinically importance difference in KOOS, JR scores, EQ-5d-5L, manipulation under anesthesia, and active range of motion was found between the control PT group and high-compliance nor low-compliance SDR groups at up to 12 months postoperatively. This combined SDR program can be considered a viable alternative to traditional PT after TKA.
Goel et al. (38)	Fitbit Charge HR and Apple Health Application	Both the smartphone application and Fitbit device were used for step count measurements.	Observational	12 TKA patients and 13 THA patients	Determine the optimal anatomical placement of activity monitoring devices and smartphones to accurately measure postoperative step count following TJA.	Device accuracy	Both accelerometers had unacceptable error levels early in the postoperative period, but the Fitbit on the contralateral ankle and iPhone on the contralateral hip showed acceptable error rates less than 30% at 2 weeks postoperatively when gait is normalizing.
Van Dijk-Huisman *et al.* (26)	MOX activity monitor and Hospital Fit app	The Hospital Fit app receives data on minutes standing and walking from the accelerometer and provides a tailored exercise program to the patient and feedback to both the patient and provider.	Non-randomized experimental study	64 TKA patients and 33 THA patients	Determine if introducing a smartphone app linked to an accelerometer to standard physiotherapy can lead to a change in physical activity of hospitalized patients following elective TJA.	Physical activity promotion	Hospital Fit app use, corrected for age, resulted in patients standing and walking on POD1 by an average increase of 28.43 min and 3.08 times higher odds of achieving functional recovery on POD1. This platform demonstrated an ability to improve TJA patient physical activity and functional recovery during hospitalization.

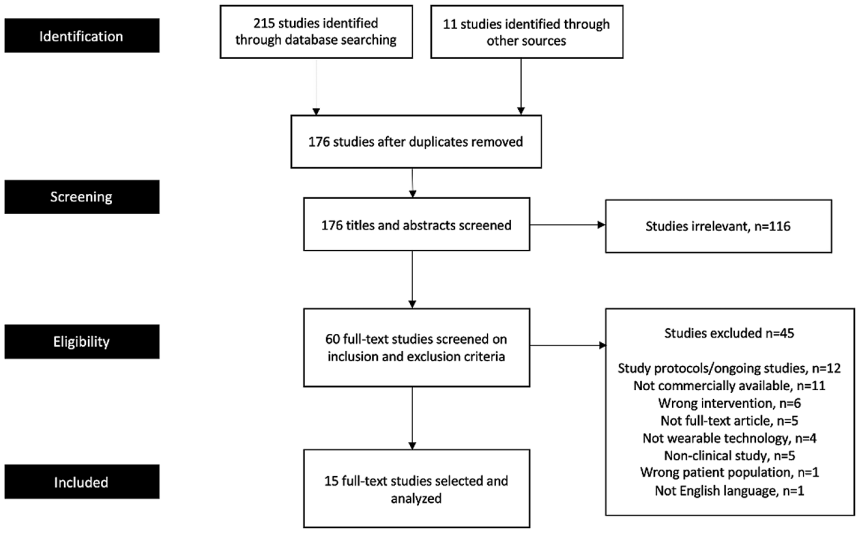

Figure 1
PRISMA flowchart.

domains of confounding, selection of participants, and missing data were most associated with moderate or serious risk of bias.

Discussion

Commercially available smartphone apps and wearable devices have demonstrated clinical value in multiple medical settings through activity monitoring and physical activity reinforcement. Orthopedics, and specifically knee replacement, has fallen behind compared to fields such as neurology, endocrinology, and cardiology (21, 22, 23). The purpose of this systematic review is to identify all studies which used commercially available wearable devices and smartphone apps to measure physical activity and monitor patient status following TKA.

Multiple studies evaluated this technology's ability to increase physical activity following TKA. In two RCTs, self-directed rehabilitation with a wearable device linked to a smartphone app showed non-inferiority to standard rehabilitation following TKA (24, 25). A third non-RCT showed that, when added to standard physiotherapy, a similar activity monitor linked to a smartphone app could improve physical activity in hospitalized patients prior to discharge (26). These studies demonstrate the potential value of such combined interventions as a replacement or adjunct to traditional rehabilitation in both the hospital and home setting.

Additionally, two RCTs showed that setting daily step goals may increase the value of these devices. Van der Walt *et al*. showed setting daily step goals and using wearable devices that provide step count feedback can significantly increase daily step count up to 6 months postoperatively (27). Mehta *et al*. showed that goal setting and connection to care teams significantly reduced rehospitalizations (28).

Studies also explored smartphone apps' ability to impact outcomes by creating patient engagement platforms. The PainCoach app improved pain control and decreased opioid use in the 2 weeks following TKA (29). The Moves

Table 4 Summary of the risk of bias assessments for included studies.

Reference	Tool used	Judgement of risk of bias across domains
Crawford *et al.* (24)	RoB 2.0	The study is judged to be at **some concern** in the domain of deviation from intended interventions
Pronk *et al.* (29)	RoB 2.0	The study is judged to be at **some concern** in the domain of deviation from intended interventions
Timmers *et al.* (31)	RoB 2.0	The study is judged to be at **some concern** in the domain of deviation from intended interventions
Tripuraneni *et al.* (25)	RoB 2.0	The study is judged to be at **some concern** in the domain of measurement of outcomes
Van der Walt *et al.* (27)	RoB 2.0	The study is judged to be at **some concern** in the domain of deviation from intended interventions
Mehta *et al.* (28)	RoB 2.0	The study is judged to be at **some concern** in the domain of missing outcomes data
Castle *et al.* (37)	ROBINS-I	This study is judged to be at **low risk of bias** across all domains
Goel *et al.* (38)	ROBINS-I	The study is judged to be at **low or moderate risk of bias** for all domains
Kelly *et al.* (35)	ROBINS-I	The study is judged to be at **low or moderate risk of bias** for all domains
Lyman *et al.* (30)	ROBINS-I	The study is judged to be at **serious risk of bias** in the domain of selection of participants but not at critical risk of bias in any domain
Twiggs *et al.* (32)	ROBINS-I	The study is judged to be at **low or moderate risk of bias** for all domains
Van Dijk-Huisman *et al.* (26)	ROBINS-I	The study is judged to be at **low or moderate risk of bias** for all domains
Vaughn *et al.* (39)	ROBINS-I	The study is judged to be at **low or moderate risk of bias** for all domains
Bini *et al.* (34)	ROBINS-I	The study is judged to be at **low or moderate risk of bias** for all domains
Patterson *et al.* (33)	ROBINS-I	The study is judged to be at **low or moderate risk of bias** for all domains

app successfully collected complete 6-month follow-up data from 68% of patients, a rate that was considered satisfactory by the authors (30). When creating these app-based platforms, priority should be placed on creating personalized information based on the user's postoperative day, which was shown to increase physical functioning and decrease pain compared to standard informational apps (31). This technology may effectively improve patient connection to information, their health, and clinicians.

Multiple studies used wearable device data to map trends in recovery relative to preoperative and postoperative characteristics (32, 33, 34). In these studies, preoperative step count, change in step count, and postoperative step count were all used to predict patient recovery (32, 33, 34). As commercially wearable technology is an exceptionally fast-growing market (18), these findings suggest value in leveraging passively collected step data from patients before surgery. While more research needs to be done to set data-driven, individualized benchmarks, wearable data can be a clinically viable alternative to predict recovery outcomes and identify complications earlier.

The question of patient compliance with monitoring was a central theme in the studies. The observational study by Lyman *et al*. found that a smartphone app following TKA was able to collect step data on a median of 92% of days for men and 86% of days for women for 6 months following surgery (30). However, this study excluded a high proportion of patients who do not usually carry their phones, which may have biased the results toward greater compliance. A separate observational study found that older age and wearing devices as clip-ons were associated with lower patient compliance in activity monitoring in the first two postoperative weeks (35). As patient mobility is reduced after surgery, that study recommended the use of more lenient compliance criteria, such as >0 steps per day, and the wearing of devices on the wrist to improve patient compliance with monitoring. Multiple studies mentioned privacy concerns as a reason for patient non-participation. Issues surrounding data security remain for many mHealth applications (36). Clinicians and researchers should discuss these concerns with patients and develop strong protocols for data security and anonymization.

Multiple studies also analyzed the accuracy of smartphones and wearable devices when measuring physical activity. The Dr Goniometer app was shown to have high concurrent reliability and validity, offering a way to remotely monitor knee ROM following TKA (37). When measuring step counts, Goel *et al*. found an Apple iPhone 6 and Fitbit Charge HR to have an acceptable error rate under 30% when worn on the contralateral hip or contralateral ankle, respectively, 2 weeks postoperatively (38). However, in this study, all step-counting devices showed unacceptable error rates directly after surgery. These findings potentially limit the use of these devices in the immediate postoperative period. They also suggest that the optimal location for user compliance, wrist, may conflict with the optimal location for accuracy, contralateral ankle.

These questions regarding accuracy and compliance when using this technology should be balanced with the stated need for improved objective measures of recovery following TKA. While subjective markers like PROMs can be valuable clinical tools, concerns about their exclusive use as a measure of recovery have been stated in the literature (5, 6). The findings of Vaughn *et al*. showed the mean error of TKA patient self-reporting of step counts >50% in both the preoperative and postoperative period (39). In this context, the ability to objectively and remotely monitor patient step count and knee ROM has significant potential clinical benefit.

Analysis of gait kinematics was not performed in the included studies. Assessment of movement quality using spatial-temporal gait parameters (STGP) has proven applications in measuring fall risk, monitoring postoperative changes in mobility, and optimizing treatment plans (40, 41, 42). Several studies that did not meet inclusion criteria for this review for using non-commercially available technology analyzed the ability of different combinations of wearable accelerometers to measure STGPs (43, 44, 45). These studies found that sensor-based gait analysis may be able to help predict clinical measures in individuals following TKA. In the future, wearable devices could remotely track gait kinematics to better monitor patient recovery kinetics following surgery.

The market for commercial wearables and smartphone apps is rapidly evolving and clinicians should be aware of updates in the industry. In recent years, multiple wearable device-app combination products designed specifically for TKA recovery, such as the Breg Flex, MotionSense, and Tracpatch, have entered the market and are undergoing clinical trials to demonstrate their efficacy (46, 47). As more studies are published, there are tools available to clinicians to help them judge the fitness of these devices and others for their patients and research. In recent years, the Consumer Technology Association has published performance criteria to evaluate the device's step counting, sleep tracking, and heart rate monitoring (48, 49, 50). A guideline by Bunn *et al.* was published to help standardize the process of evaluating devices (18). In 2017, the FDA announced the creation of its Software Precertification Pilot Program as a new effort to evaluate digital health products (51). Nine companies were selected for the pilot program, including leading wearable device manufacturers such as Apple, Fitbit, and Samsung. Moving forward, this process may offer more transparency on the risks and benefits of products entering the market.

We recognize several limitations in this study. The first is the overall strength of the evidence presented in the study. Six of the 15 studies were level II evidence RCTs, but all had

some concerns for bias in at least one domain. The other seven studies were level III to level VI evidence. One study showed serious risk of bias in the domain of selection of participants. Additionally, only two studies commented on the economic impact of these interventions (24, 28). Greater cost savings from these technologies must be demonstrated before sustained uptake by health systems can be expected. Finally, only one study in this review measured follow-up to 1 year (25). Thus, this review is limited in its ability to analyze the long-term impact of this technology on recovery. Finally, this review excluded non-commercially available technology. Devices available to institutions only and lent out to patients during recovery may be viable alternatives that should be assessed in the future.

The studies included in this review show that commercially available smartphone apps and wearable devices can feasibly be used as an alternative or adjunct to traditional rehabilitation following TKA. Components such as device feedback, incorporation of patient engagement platforms, and preoperative step count monitoring to set patient-specific benchmarks for recovery may provide additional clinical benefit. Future research should explore areas such as economic impact of this technology and its long-term impact on patient recovery. Questions surrounding compliance and accuracy of this technology remain. Future research should aim to study ways to optimize both compliance and accuracy when using individual devices.

Conclusions

Current evidence suggests commercially available smartphone apps and wearable devices can potentially improve remote assessment of physical activity and incentivize patient activity and engagement following TKA. Components of interventions such as step goals, app-based patient engagement platforms, and patient-specific benchmarks for recovery may improve effectiveness. However, a paucity of evidence supporting the long-term efficacy and economic impact of this technology remains. Future research should focus on the economics of implementation, long-term outcomes, and optimization of compliance and accuracy when using these devices. The goal of these technologies should be focused on demonstrating that these devices can enhance traditional monitoring strategies, assist with rehabilitation goals, improve complication detection, and reduce institutional costs.

ICMJE Conflict of Interest Statement

V H declares paid consultation for Stryker, Pfizer, and Consensus, as well as roles as a voting member of the AAHKS International Committee and Editor of JBJS CME. The other authors declare that there is no conflict of interest that could be perceived as prejudicing the impartiality of this study.

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