Using Wearable Technologies to Monitor Physical Activity and Exercise in Patients: A Narrative Review

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Abstract

With an increasing prevalence of sedentary lifestyles driving a prominent public health crisis, digital health tools such as wearable technologies are revolutionizing clinicians' ability to track physical activity and exercise. Despite their ubiquity in the consumer market, these technologies have not yet been fully incorporated into clinical practice. Though these tools promise efficacy and accessibility, a careful review of the current literature is important to understand the challenges and future promise of clinical implementation. Important considerations of implementation include health maintenance and disease prevention, ease of use by patients and providers, incorporation into the electronic health record, cost considerations, safety, privacy, and ethical considerations. This narrative review describes the recent literature on the implementation of wearable technologies in the prescription of physical activity and exercise. Application of these technologies is promising for this field's future.

Introduction

Sedentary lifestyle is an increasingly prominent public health crisis — one-third of the global population aged 15 years and older engages in an insufficient level of physical activity (1). The mean daily duration of sedentary behavior in the American adult population is 7.7 hours daily (1). Sedentary behavior is associated with heart disease risk, obesity, chronic inflammation, metabolic syndrome, and increased all-cause mortality (1). In 2018, the U.S. Department of Health and Human Services (USDHHS) reported that approximately $117 billion (about $360 per person in the United States) in annual health care costs and 10% of premature deaths are attributed to sedentary lifestyles (2). Lack of physical activity is considered the fourth leading risk factor for global mortality, associated with 30% of ischemic heart disease worldwide (3). Reducing sedentary behavior by encouraging physical activity is critical to promoting public health. The American College of Sports Medicine (ACSM) currently recommends at least 150 min of moderate-intensity aerobic physical activity per week for adults aged 18 to 65 years (4). The Exercise is Medicine® initiative of ACSM has been developed to increase the assessment and prescription of physical activity as part of routine clinical care. It is evident that physical activity and exercise have beneficial effects on health maintenance and disease prevention.

Digital health tools including wearable activity tracking devices can be useful tools for clinicians to monitor and promote physical activity and exercise. These devices provide real-time feedback, which can be used to motivate patients to increase their activity (3,5–7), improve functional status (8–10), and boost health outcomes (11–13). Current studies involving implementation of wearable technologies have shown overall improvement of patient-reported outcomes, including step count, gait speed, and flights of stairs (9,11,14). Given the growing interest to understand the clinical applications of wearable technologies, the aim of this paper is to provide a comprehensive summary of the current literature on digital health, including wearable devices for physical activity and exercise monitoring in the outpatient setting.

The predominant themes in this review include 1) the role of wearable devices in health maintenance and disease prevention, 2) incorporation into the electronic health record (EHR), 3) patient and provider usability experience, 4) cost considerations and coding and billing, 5) limitations of wearable technologies, and 6) future considerations regarding privacy and the role of artificial intelligence (AI).

Methods

Data Collection and Analysis

We conducted a narrative review of the current literature (published after March 2023) regarding mobile apps and wearable technologies and their applications to patient physical activity and exercise. Due to the rapidly evolving literature, findings were limited to the past year to provide a focused review of the most current literature regarding wearable technologies. The

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literature review was conducted in the National Library of Medicine's PubMed Central® online database (13). The inclusion criteria were as follows: 1) original articles; 2) published after March 1, 2023, to provide a focused review of the most current literature in a rapidly evolving field; 3) exploring either mobile apps or wearable technology in the prescription of physical activity in patients; and 4) adult population. As diagrammed in Figure 1, an initial search of papers involving "wearable trackers" OR "wearable technologies" yielded 26,918 results. Adding "physical activity" AND "exercise" AND "patients" AND "clinical" and narrowing search results to those published after March 1, 2024, yielded 49 results. Eighteen papers were excluded for the following reasons: 1) conducted in a closed hospital setting (*e.g.*, ICU, inpatient rehabilitation facility) or 2) measured a parameter other than physical activity (*e.g.*, oxygen saturation, blood flow, lung volume). The final number of papers reviewed was 31.

The following Boolean logic advanced search parameters were used in PubMed Central in March 2024: "((((((wearable trackers) OR (wearable technologies)) AND (physical activity)) AND (exercise)) AND (("2023/03/01"[Date - Entry]: "3000"[Date - Entry]))) AND (patients)) AND (clinical)."

Results

Electronic Health Record Integration

While wearable technologies are used by consumers recreationally to track physical activity and exercise, there is an emerging case for using them in clinical prescription as well. Current studies demonstrate the feasibility of smart device apps and websites for prescribing exercise videos in combination with wearable devices to monitor health parameters; however, they acknowledge the exploratory stage of these studies (14). For example, smartphone apps used for the prescription of exercises have been predominantly tested in small, homogeneous populations with a specific diagnosis such as heart failure or endometrial and colorectal cancers. Though only a few studies have assessed optimal integration of wearable technologies into clinical practice, their use is growing, and more data are emerging to facilitate the meaningful clinical integration of these metrics into the EHR.

Despite the ubiquity of physical activity consumer wearables, incorporation into clinical care has been adopted more slowly. An analysis of stakeholder opinion on clinical implementation highlighted data standardization as a major barrier, acknowledging the vast selection of commercially available devices and sensor locations, as well as the lack of standards for data integration into the EHR and clinical workflow (15). Standardization of complex data sets (*e.g.*, Fitabase, Clarivate Analytics, dbt Labs) requires preselected outcome measures and the assistance of a researcher or data manager who can help monitor the variables, address data outliers, and monitor for and address abnormal data points; though relevant for research use, this is not practical in the patient care setting (16). Challenges of integrating data from wearable technologies into the EHR mirror the need for standard data formats.

The Health Level 7 (HL7) Fast Healthcare Interoperability Resources (FHIR) is a next-generation interoperability standard created by standard development organization HL7 to enable health data — both clinical and administrative — to be quickly and efficiently exchanged (17). Development of this standard aims to facilitate adoption across disparate developer

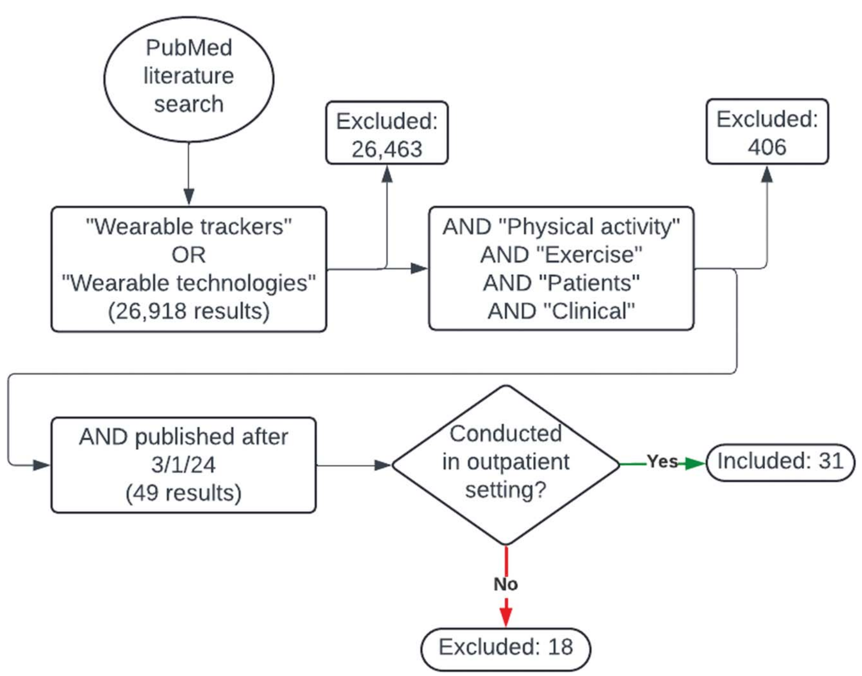

Figure 1: CONSORT flow diagram demonstrating selection and exclusion of papers for narrative review. Initial PubMed literature search of "wearable trackers" OR "wearable technologies" yielded 26,918 results. When narrowed to include "physical activity" AND "exercise" AND "patients" AND "clinical," 26,463 studies were excluded. Of these 455 studies, 49 were published after March 1, 2024. The 18 papers were excluded for the following reasons: 1) conducted in a setting other than outpatient (*e.g.*, closed hospital setting, ICU, inpatient rehabilitation facility); 2) wearable technology measured a parameter other than physical activity (*e.g.*, oxygen saturation, blood flow, lung volume).

communities, reduce the learning curve, enable faster and simpler application creation, and enable continuity with existing provider workflow (17). Emerging studies have explored feasible ways to transform health data from wearable technologies — starting with Fitbit® data — to standardized JavaScript Object Notation (JSON) files following the Open mHealth (OmH) Institute of Electrical and Electronics Engineers (IEEE) and the HL7 FHIR standard (18). The process of data collection and integration is outlined in Figure 2. Patient physical activity is first collected using wearable technologies such as wristbands, smartwatches, and mobile sensors. Data are collected through sensors in apps that communicate with application programming interfaces (APIs), a set of functions that allows for standardized collection of data. These data are then shared through data aggregators (*e.g.*, Apple's HealthKit®, Fitbit®) that pool data from multiple apps. Compiled data are integrated into the EHR, which are then made available to providers for clinical decision-making (19). One goal of these technologies is to forge a partnership between patient and provider to increase physical activity and incentivize patients to take a more proactive role in their overall health.

Patient Usability (*e.g.*, Comfort, Wearability)

Wearable devices can be implemented across a wide range of diseases and patient populations. A common consideration for the use of these technologies is patient usability — whether patients are motivated to use wearable devices consistently and effectively integrate them into their daily lives over time. Development of personalization strategies is an area ripe for innovation to increase patient engagement and avoid wearables "fatigue" (15). For example, in a remote glucose monitoring program at Kaiser Permanente, allowing patients to opt in or out of add-on features was identified as an important aspect of end-user design, as it led to significant improvements in patient engagement and ultimately improved medical management (15). In a study testing the feasibility of a smartphone app for prescribed exercise tutoring in patients with stable coronary heart disease, exercise demonstration videos were suggested to improve patients' motivation to exercise at home (14). Other notable features designed to enhance patient usability and increase interaction included 1) progressive personalized physical activity goals, 2) semiautomated clinician feedback on physical activity progress, 3) encouraging feedback messages tailored to goal attainment, and 4) strategies targeting social cognitive theory constructs to teach patients skills for setting goals and overcoming barriers (20). In one study, participants were encouraged to discuss progress at medical appointments, and the care team was provided automatically generated talking points tailored to the patient's progress, as well as monthly summary emails of each patient's progress. Combined, these messages enhanced patients' self-efficacy via social persuasion (20).

Other considerations for patient factors in wearable technologies include age, gender, and education (21). Secondary analysis of data from the National Cancer Institute's 2015 Health Information National Trends Survey (HINTS) suggested that attainment of higher education reflects skills and confidence with the use of devices in addition to internalization of social norms related to the perceived value of being healthy (22). While there was no significant difference in the frequency of use of wearable technologies between males and females, men appeared to prefer user functions directly related to exercise (*e.g.*, sensors, GPS, and journaling), and women preferred apps with a focus on general health (*e.g.*, nutrition and self-care) (21). In a study of patients in Mongolia and China, it was found that older adults tended to use mobile health apps less frequently and were overall disadvantaged regarding mHealth access and use, as were subgroups with lower levels of education (23). Individualization, education, and distribution of wearable technologies will be essential to eventual integration as a clinical tool.

Provider Usability

By providing a more accurate measure of physical activity level and improving patient behavior change around physical activity, digital health devices can provide clinicians with a more comprehensive understanding of patients' health, enabling an individualized approach to patient care (24). A randomized controlled trial conducted at a regional orthopedic medical center in China evaluated the effectiveness of using wearable monitoring devices for rehabilitation exercise after total knee arthroplasty (25). Notable in this study was the ease of provider usability — the wearable devices both monitored exercise data and uploaded it to physician's workstations for review. The authors cited the automation and remote nature of this process as ways to overcome geographic barriers in growing and aging populations (25). Additionally, device-based measures of physical activity enabled more thorough analyses and insights into specific patterns of physical activity. Most importantly, direct delivery of physical activity monitoring confers enhanced efficiency to provider workflow.

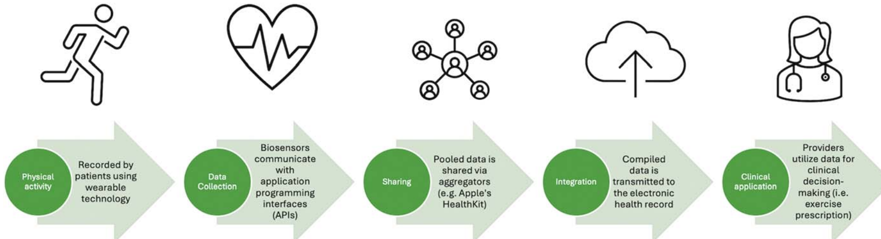

Figure 2: Flowchart of data collection and integration from wearable devices to the electronic health record and clinical application. The interoperability of these data between third-party products and the electronic health record is required for automated presentation of the data to providers. Ultimately, the goal is to have this process be completely automated once the patient has downloaded the appropriate applications and provided sharing permissions.

A potential barrier to the adoption of activity trackers as a clinical tool to increase physical activity or exercise may be the minimal exposure to these resources in medical education. A review of e-health technology in cardiac exercise interventions noted the lack of exercise education in most pediatric residencies and pediatric cardiology fellowship programs (26). Widespread adoption of digital health into the clinical ecosystem requires a foundation of understanding from a trainee level. Simultaneously, there is a need to incorporate education of physical activity promotion, monitoring, prescription, and intervention into the standard training of health care providers (26).

Provider usability also depends on the ability to leverage data from activity trackers to make clinical decisions. The transmission of data between wearable devices and the EHR has become more automated due to interoperability standards (*i.e.*, FHIR HL7) (17). Once these data are collected and integrated into the EHR, they can be used to support clinical decision-making. For example, a patient may have a sudden decrease in daily step count that triggers a phone notification asking 1) if anything has happened that has impacted their ability to exercise and 2) if they would like to schedule a clinic visit. Alternatively, instead of having patients describe their activity since the last visit, the provider could review a summary of the activity data that already exist in their health record. Improving interoperability and clinical decision support mechanisms between wearable devices and the EHR will in turn improve provider usability.

Cost Considerations

Currently, the cost of consumer wearables ranges from less than $100 to around $400, with the average wearable costing $100 to $200 USD (27). Most insurance companies do not cover wearables for patients, which leaves the cost burden to the patient and results in cost-driven self-selection of wearable technology users. However, to justify insurance coverage, there needs to be evidence substantiating the benefits of incorporating wearable technologies into clinical care and billing and reimbursement pathways (27). To date, there is insufficient published data on the return on investment (*i.e.*, reduction in cost of care) of integrating these devices for routine physical activity monitoring in clinical practice. However, emerging remote clinical studies involving wearable technologies at Kaiser (15) suggest that the potential for fewer clinical visits and thus fewer copayments along with reduced time invested in appointments and travel to clinics would be strong motivators for initial adoption by patients. Home-based exercises (*i.e.*, supervised or unsupervised) are preferred by patients who were recently discharged home after through-knee amputations due to convenience (28–30). Systematic reviews and meta-analyses have further confirmed that supervised rehabilitation exercises do not provide additional benefits when compared to home-based rehabilitation exercises (31–33). It is evident that reducing costs and improving care efficiency are important objectives in rehabilitation programs; home-based rehabilitation can lower costs for both patients and providers, which aligns with the needs of value-based care (31,32).

Reimbursement Strategies (*e.g.*, Billing/Coding/RPM CPT Codes)

Medicare CPT codes exist for remote patient monitoring (RPM) and remote therapeutic monitoring (RTM). RPM focuses on collecting and monitoring physiological data such as vital signs using FDA-approved devices, whereas RTM acquires nonphysiological, patient-reported data on indicators and outcomes such as musculoskeletal status or medication adherence and therapy response. To date, physical activity measures such as step count, sedentary time, and active minutes are not considered physiological measures billable under RPM (34,35). However, PA measures could be tracked in addition to currently covered physiological measures such as heart rate, blood pressure, glucose monitoring, and others.

In addition to careful consideration of reimbursement strategies and impact on population health, having provider champions of digital health incorporation of PA measures will be critical in successful integration into the clinical ecosystem. The Ochsner Health System and Kaiser Permanente have each designed digital health programs for the management of hypertension and diabetes, respectively (36). Each system identified a champion provider at a single clinical site to beta test, provide feedback, and help optimize initial clinical use. This provider helped pilot demonstrations of the program's effectiveness; from here, the program was then made available to other providers at this site on an opt-in basis. Once buy-in from multiple providers was established at this first site, the program was then scaled to other sites within the health system. Despite no direct financial compensation for integrating these measures, an internal assessment of provider attitudes revealed that adoption was motivated by improved efficiency of care rather than by perceived financial reward or incentive (15).

Limitations of Digital Health

While many wearable technology studies have reported minimal adverse events associated with the intervention, there is a lack of uniform protocols for safety-related event monitoring (37). Inclusion criteria vary, and patients with multimorbidity are often excluded from these studies. Reliance on patient reports makes close communication between patient and provider even more crucial to ensuring participant safety. Additionally, involvement of a rehabilitation expert (physiatrist, physical therapist, sports medicine, or exercise physiologist) is helpful in assessing medical comorbidities to personalize an exercise program to a patient's fitness level. One remote cardiac rehabilitation program conducted cardiopulmonary exercise testing prior to starting patients in the program. Patients were instructed not to exceed a rating of 13 ("somewhat hard") on the Borg Rate of Perceived Exertion (RPE) scale, an intensity that correlates with the anaerobic threshold level of an exercise load (38). Patients were permitted to exercise only if they had no problems within a 12-item checklist including the following: fever; feeling tired; nausea or feeling sick; ringing in the ears; feeling ill with sleep deprivation; loss of appetite; diarrhea, constipation, or stomach pain; have a cold; heart palpitations and shortness of breath with low levels of exercise; and chest pain with low levels of exercise (39). This study highlights the importance of safety monitoring in the use of wearable technologies, especially when physical activity prescription often relies on participants to self-report adverse symptoms.

A systematic review of wearable devices in cardiovascular disease populations cited reasons why activity tracking using accelerometers or GPS could be prone to error: wrist-worn wearable devices utilizing accelerometer data may misclassify sedentary time as step count if the patient is moving their arms while seated or on an arm-powered bike, and accuracy of GPS activity tracking is impacted by the strength and consistency of the GPS signal (*e.g.*, activity tracking may be underestimated in urban or highly forested areas subject to weaker signal strength) (40–42). On the other hand, patients living in rural or remote areas may be limited by wireless service accessibility and limited data capacity, though they may benefit from a remote digital health program (15).

In addition to technological limitations of wearable technologies, there are considerations from a legislative perspective. The U.S. Food and Drug Administration defines Software as a Medical Device (SaMD) as "software intended to be used for one or more medical purposes that perform these purposes without being part of a hardware medical device" (13). When data from wearable technologies is pooled into aggregators for integration into the EHR, they are extending beyond the hardware limitations of traditional medical devices and can be considered SaMD. International regulators recognize the need to unite under a common framework and principles for SaMD — the International Medical Device Regulators Forum (IMDRF) is a voluntary group developed internationally to establish agreed upon regulations. These include key definitions (43), framework for risk categorization (43), quality management, and clinical evaluation of SaMD (44). The goal of these guidelines is to provide clarity and predictability for manufacturers, patients, and providers alike. Risk analysis, equitable distribution, and regulatory standards remain important considerations for implementation of wearable technologies.

Privacy and Ethical Considerations

An emerging potential "Achilles heel" of wearable devices is the security of recorded activity, location, and health information of patients. Incorporation of epidermal sensors in wearable devices has enabled passive collection of a wide range of biometric data. Real-time, continuous transmission of data to cloud storage can be achieved with swift, wireless communication technologies such as Near Field Communication (NFC), Bluetooth, and Wi-Fi. Such instantaneous, personalized data sharing is uniquely advantageous for individualized health interventions but raises concern over the privacy and data security of its users. It is important for both technology developers and providers to incorporate regulatory considerations when designing and implementing these changes.

Another component of ethical implementation involves equitable distribution of devices. Based on current published studies, wearable device users are more likely to be younger, Caucasian, wealthier, and of higher educational status compared to people without devices (45). However, racial and ethnic minorities, along with patients of lower socioeconomic status, more frequently do not meet the recommend levels of regular physical activity. Combined with the prevalent "bring your own device" participant recruitment strategy of many wearable device studies, these trends in technology ownership perpetuate disparities in participant demographics of scientific studies investigating use of wearable devices in health outcomes (46). The long-term clinical effects of these structural inequities are not fully understood, highlighting further need for studies across more diverse socioeconomic populations (47).

Application of Artificial Intelligence in Wearable Devices

Artificial intelligence (AI) and machine learning (ML) have the potential to transform health care technologies by leveraging existing data generated through routine patient care. In the realm of wearable technology, ML is a powerful tool that can transform motion signals from devices into variables such as posture, activity type, and intensity and duration of physical activity (48,49). While previous methods of measurements and categorization of movement relied heavily on conventional statistical approaches, integration of ML methodologies ushers in a new era of more complex movement behaviors and postures from wearables — several studies have demonstrated these enhanced predictive capabilities of ML in determining activity types, intensity levels, and energy expenditure compared to other statistical methods (49,50).

Currently, the U.S. FDA has four areas of focus regarding the use of AI across medical products: 1) foster collaboration to safeguard public health; 2) advance the development of regulatory approaches that support innovation; 3) promote the development of harmonized standards, guidelines, best practices, and tools; and 4) support research related to the evaluation and monitoring of AI performance. Deployment of AI in the realm of digital health requires responsible and ethical use of medical products that use AI (51).

Conclusion

Wearable technologies are changing the way both patients and providers approach prescription of physical activity and exercise. There are clear advantages including individualized health management, increased motivation, and strengthened patient participation in their own health care (19,25). However, nuances of implementation also must be considered, including patient and provider usability and adoption, data security, privacy, and ethical implementation of wearable technologies. From a systemic viewpoint, incorporation into the EHR requires system buy-in and champion providers. Overall, wearable technologies have great potential in the prescription of physical activity. A balanced approach that integrates wearables into comprehensive wellness strategies may become central to promoting patient health and well-being.

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References

1. Park JH, Moon JH, Kim HJ, *et al*. Sedentary lifestyle: overview of updated evidence of potential health risks. *Korean J. Fam. Med*. 2020; 41:365–73.
2. United States. *Department of Health and Human Services. Physical Activity Guidelines for Americans*. 2nd ed. U.S. Dept. of Health and Human Services: Washington (DC); 2018.
3. Carter L, Ford CD. Promoting physical activity in clinical practice through wearable technology. *J. Am. Assoc. Nurse Pract*. 2023; 35:765–9.
4. Trending Topic | Physical Activity Guidelines [Internet]. American College of Sports Medicine; 2020 [cited 2024 April 22]. Available from: https://www.acsm.org/education-resources/trending-topics-resources/physical-activity-guidelines.
5. Lu L, Zhang J, Xie Y, *et al*. Wearable health devices in health care: narrative systematic review. *JMIR Mhealth Uhealth*. 2020; 8:e18907.
6. Lee IM, Keadle SK, Matthews CE. Fitness trackers to guide advice on activity prescription. *JAMA*. 2023; 330:1733–4.
7. Fanaroff AC, Patel MS, Chokshi N, *et al*. A randomized controlled trial of gamification, financial incentives, or both to increase physical activity among patients with elevated risk for cardiovascular disease: rationale and design of the be active study. *Am. Heart J*. 2023; 260:82–9.

8. Lee A, Dionicio P, Farcas E, *et al*. Physical therapists' acceptance of a wearable, fabric-based sensor system (motion tape) for use in clinical practice: qualitative focus group study. *JMIR Hum. Factors*. 2024; 11:e55246.
9. Christensen JC, Blackburn BE, Anderson LA, *et al*. Recovery curve for patient reported outcomes and objective physical activity after primary total knee arthroplasty-a multicenter study using wearable technology. *J. Arthroplasty*. 2023; 38(6S):S94–S102.
10. Master H, Coronado RA, Whitaker S, *et al*. Combining wearable technology and telehealth counseling for rehabilitation after lumbar spine surgery: feasibility and acceptability of a physical activity intervention. *Phys. Ther*. 2024; 104: pzad096.
11. Hardcastle SJ, Douglass E, Wilson B, Maxwell-Smith C. Experiences and facilitators of physical activity engagement amongst colorectal and endometrial cancer survivors: the Wearable Activity Technology and Action-Planning (WATAAP) trial. *Support. Care Cancer*. 2023; 31:662.
12. Aix SP, Núñez-Benjumea FJ, Cervera-Torres S, *et al*. Data-driven personalized care in lung cancer: scoping review and clinical recommendations on performance status and activity level of patients with lung cancer using wearable devices. *JCO Clin. Cancer Inform*. 2023; 7:e2300016.
13. PubMed Advanced Search Builder [Internet]. U.S. National Library of Medicine: National Center for Biotechnology Information; [cited April 22, 2024]. Available from: https://pubmed.ncbi.nlm.nih.gov/advanced/.
14. Xia K, Bai C, Ding R, *et al*. Feasibility of a smartphone app for prescribed exercise tutoring in patients with stable coronary heart disease. *Digit. Health*. 2023; 9:20552076231197424.
15. Smuck M, Odonkor CA, Wilt JK, *et al*. The emerging clinical role of wearables: factors for successful implementation in healthcare. *NPJ Digit. Med*. 2021; 4:45.
16. Ragland C. Avoid data overload and turn your data into results [Internet]. Clear Impact; [cited April 16, 2024]. Available from: https://clearimpact.com/fix-data-overload/.
17. Health Level 7 (HL7) Fast Healthcare Interoperability Resources (FHIR) [Internet]. The Office of the National Coordinator for Health Information Technology (ONC); [cited April 24, 2024]. Available from: https://www.healthit.gov/topic/standards-technology/standards/fhir.
18. Falkenhein I, Bernhardt B, Gradwohl S, *et al*. Wearable device health data mapping to open mHealth and FHIR data formats. *Stud. Health Technol. Inform*. 2023; 305:341–4.
19. Dinh-Le C, Chuang R, Chokshi S, Mann D. Wearable health technology and electronic health record integration: scoping review and future directions. *JMIR Mhealth Uhealth*. 2019; 7:e12861.
20. Cadmus-Bertram L, Solk P, Agnew M, *et al*. A multi-site trial of an electronic health integrated physical activity promotion intervention in breast and endometrial cancers survivors: MyActivity study protocol. *Contemp. Clin. Trials*. 2023; 130:107187.
21. Oba T, Takano K, Katahira K, Kimura K. Use patterns of smartphone apps and wearable devices supporting physical activity and exercise: large-scale cross-sectional survey. *JMIR Mhealth Uhealth*. 2023; 11:e49148.
22. Carroll JK, Moorhead A, Bond R, *et al*. Who uses mobile phone health apps and does use matter? A secondary data analytics approach. *J. Med. Internet Res*. 2017; 19:e125.
23. Cao L, Chongsuvivatwong V, McNeil EB. The sociodemographic digital divide in mobile health app use among clients at outpatient departments in inner Mongolia, China: Cross-sectional Survey Study. *JMIR Hum. Factors*. 2022; 9: e36962.
24. Hodgson W, Kirk A, Lennon M, *et al*. RE-AIM (Reach, Effectiveness, Adoption, Implementation, and Maintenance) evaluation of the use of activity trackers in the clinical care of adults diagnosed with a chronic disease: integrative systematic review. *J. Med. Internet Res*. 2023; 25:e44919.
25. Yang C, Shang L, Yao S, *et al*. Cost, time savings and effectiveness of wearable devices for remote monitoring of patient rehabilitation after total knee arthroplasty: study protocol for a randomized controlled trial. *J. Orthop. Surg. Res*. 2023; 18:461.
26. White DA, Layton AM, Curran T, *et al*. ehealth technology in cardiac exercise therapeutics for pediatric patients with congenital and acquired heart conditions: a summary of evidence and future directions. *Front. Cardiovasc. Med*. 2023; 10: 1155861.
27. Somani SN, Yu KM, Chiu AG, *et al*. Consumer wearables for patient monitoring in otolaryngology: a state of the art review. *Otolaryngol. Head Neck Surg*. 2022; 167:620–31.
28. DeMik DE, Carender CN, Glass NA, *et al*. Home discharge has increased after total hip arthroplasty, however rates vary between large databases. *J. Arthroplasty*. 2021; 36:586–92.e1.
29. Hutchinson AG, Gooden B, Lyons MC, *et al*. Inpatient rehabilitation did not positively affect 6-month patient-reported outcomes after hip or knee arthroplasty. *ANZ J. Surg*. 2018; 88:1056–60.
30. Martina K, Hunter DJ, Salmon LJ, *et al*. Surgery for osteoarthritis: total joint arthroplasty, realistic expectations of rehabilitation and surgical outcomes: a narrative review. *Clin. Geriatr. Med*. 2022; 38:385–96.
31. Florez-Garcia M, Garcia-Perez F, Curbelo R, *et al*. Efficacy and safety of home-based exercises versus individualized supervised outpatient physical therapy programs after total knee arthroplasty: a systematic review and meta-analysis. *Knee Surg. Sports Traumatol. Arthrosc*. 2017; 25:3340–53.
32. Bravi M, Longo UG, Laurito A, *et al*. Supervised versus unsupervised rehabilitation following total knee arthroplasty: a systematic review and meta-analysis. *Knee*. 2023; 40:71–89.
33. Mahomed NN, Davis AM, Hawker G, *et al*. Inpatient compared with home-based rehabilitation following primary unilateral total hip or knee replacement: a randomized controlled trial. *J. Bone Joint Surg. Am*. 2008; 90:1673–80.
34. Mastering Medicare RPM Reimbursement: Your Guide to CPT Codes for RPM [Internet]. TriageLogic; [cited April 22, 2024]. Available from: https://triagelogic.com/guide-to-cpt-codes-for-rpm/.
35. Medicare and Medicaid Programs; CY 2024 Payment Policies Under the Physician Fee Schedule and Other Changes to Part B Payment and Coverage Policies; Medicare Shared Savings Program Requirements; Medicare Advantage; Medicare and Medicaid Provider and Supplier Enrollment Policies; and Basic Health Program [Internet]. Federal Register; [cited April 22, 2024]. Available from: www.federalregister.gov/documents/2023/08/07/2023-14624/medicare-and-medicaid-programs-cy-2024-payment-policies-under-the-physician-fee-schedule-and-other.
36. Milani RV, Lavie CJ, Bober RM, *et al*. Improving hypertension control and patient engagement using digital tools. *Am. J. Med*. 2017; 130:14–20.
37. Hunter H, Bennington-McKay N, Sher J, *et al*. Emerging role of mobile applications and wearable devices for prehabilitation in urologic oncology. *Eur. Urol. Focus*. 2024; 10:20–2.
38. Scherr J, Wolfarth B, Christle JW, *et al*. Associations between Borg's rating of perceived exertion and physiological measures of exercise intensity. *Eur. J. Appl. Physiol*. 2013; 113:147–55.
39. Nakayama A, Ishii N, Mantani M, *et al*. Remote cardiac rehabilitation with wearable devices. *Korean Circ. J*. 2023; 53:727–43.
40. Gilgen-Ammann R, Schweizer T, Wyss T. Accuracy of distance recordings in eight positioning-enabled sport watches: instrument validation study. *JMIR Mhealth Uhealth*. 2020; 8:e17118.
41. Petek BJ, Al-Alusi MA, Moulson N, *et al*. Consumer wearable health and fitness technology in cardiovascular medicine: JACC state-of-the-art review. *J. Am. Coll. Cardiol*. 2023; 82:245–64.
42. Nielsen RO, Cederholm P, Buist I, *et al*. Can GPS be used to detect deleterious progression in training volume among runners? *J. Strength Cond. Res*. 2013; 27:1471–8.
43. IMDRF Software as a Medical Device Working Group. Software as a Medical Device: Possible Framework for Risk Categorization and Corresponding Considerations. [cited April 23, 2024]. Available from: https://www.imdrf.org/sites/default/files/docs/imdrf/final/technical/imdrf-tech-140918-samd-framework-risk-categorization-141013.pdf.
44. IMDRF Software as a Medical Device Working Group. Software as a Medical Device (SaMD): Clinical Evaluation. [cited April 22, 2024]. Available from: https://www.fda.gov/media/100714/download.
45. Al-Alusi MA, Khurshid S, Wang X, *et al*. Trends in consumer wearable devices with cardiac sensors in a primary care cohort. *Circ. Cardiovasc. Qual. Outcomes*. 2022; 15:e008833.
46. Cho PJ, Yi J, Ho E, *et al*. Demographic imbalances resulting from the bring-your-own-device study design. *JMIR Mhealth Uhealth*. 2022; 10:e29510.
47. Bent B, Goldstein BA, Kibbe WA, Dunn JP. Investigating sources of inaccuracy in wearable optical heart rate sensors. *NPJ Digit. Med*. 2020; 3:18.
48. Farrahi V, Rostami M. Machine learning in physical activity, sedentary, and sleep behavior research. *J. Act. Sedentary Sleep Behav*. 2024; 3:5.
49. de Almeida Mendes M, da Silva ICM, Ramires VV, *et al*. Calibration of raw accelerometer data to measure physical activity: a systematic review. *Gait Posture*. 2018; 61:98–110.
50. Narayanan A, Desai F, Stewart T, *et al*. Application of raw accelerometer data and machine-learning techniques to characterize human movement behavior: a systematic scoping review. *J. Phys. Act. Health*. 2020; 17:360–83.
51. Artificial Intelligence & Medical Products: How CBER, CDER, CDRH, and OCP are Working Together. [cited April 23, 2024]. Available from: https://www.fda.gov/media/177030/download?attachment.