Digital Phenotyping and Patient-Generated Health Data for Outcome Measurement in Surgical Care: A Scoping Review

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Abstract: Digital phenotyping—the moment-by-moment quantification of human phenotypes in situ using data related to activity, behavior, and communications, from personal digital devices, such as smart phones and wearables—has been gaining interest. Personalized health information captured within free-living settings using such technologies may better enable the application of patient-generated health data (PGHD) to provide patient-centered care. The primary objective of this scoping review is to characterize the application of digital phenotyping and digitally captured active and passive PGHD for outcome measurement in surgical care. Secondarily, we synthesize the body of evidence to define specific areas for further work. We performed a systematic search of four bibliographic databases using terms related to “digital phenotyping and PGHD,” “outcome measurement,” and “surgical care” with no date limits. We registered the study (Open Science Framework), followed strict inclusion/exclusion criteria, performed screening, extraction, and synthesis of results in line with the PRISMA Extension for Scoping Reviews. A total of 224 studies were included. Published studies have accelerated in the last 5 years, originating in 29 countries (mostly from the USA, n = 74, 33%), featuring original prospective work (n = 149, 66%). Studies spanned 14 specialties, most commonly orthopedic surgery (n = 129, 58%), and had a postoperative focus (n = 210, 94%). Most of the work involved research-grade wearables (n = 130, 58%), prioritizing the capture of activity (n = 165, 74%) and biometric data (n = 100, 45%), with a view to providing a tracking/monitoring function (n = 115, 51%) for the management of surgical patients. Opportunities exist for further work across surgical specialties involving smartphones, communications data, comparison with patient-reported outcome measures (PROMs), applications focusing on prediction of outcomes, monitoring, risk profiling, shared decision making, and surgical optimization. The rapidly evolving state of the art in digital phenotyping and capture of PGHD offers exciting prospects for outcome measurement in surgical care pending further work and consideration related to clinical care, technology, and implementation.

Keywords: digital phenotyping; patient-generated health data; patient monitoring; activity tracking; wearables; sensors; patient-reported outcome measures; surgery
1. Introduction

Technology-enabled solutions that capture patient-generated health data (PGHD)—data related to activity, mobility, cognition, behavior, mood and social interactions—are rapidly evolving with the aim of a more personalized, patient-centered, and data-driven approach to the delivery of surgical care [1–5]. The concept of “digital phenotyping” was first coined in 2015 by J.P. Onnela as the moment-by-moment quantification of individual human phenotypes in situ using data related to activity, behavior, and communications from personal digital devices, such as smartphones and wearable sensors (wearables) [6–10]. While the first smartphones were developed around 1992, wider utilization and applications capturing PGHD occurred toward the late 2000s. The acquisition of PGHD in the form of patient-reported outcome measurements (PROMs) is commonplace in clinical research and increasingly common in clinical care. PROMs are questionnaires that quantify the patient’s perspective of their physical, emotional, and social health, and are commonly collected using tablet devices and web-based, online portals [11–15]. The electronic capture and utility of PROMs has transformed the evaluation of health outcomes in surgical research, partly due to well-defined surgical pathways and time points during the preoperative baseline to postoperative recovery and rehabilitation [12,16]. However, the adoption of PROMs in clinical practice is limited by the burden placed on patients to interpret and complete surveys, is often restricted to the clinical encounter, and associated with several administrative and logistical barriers in sustaining longitudinal data collection, especially in busy, resource-limited settings [15,17].

1.1. Rationale

The continuous capture of passive PGHD in “real time” may overcome these limitations via digital phenotyping. However, little is known around digital phenotyping and PGHD in the context of outcome measurement in surgical care. An individual’s digital phenotype and how they interact with these devices aims to provide dynamic insights around the impact of a given condition on the patient’s lived experience, both within and outside health care settings. This rich data source may augment the way we traditionally acquire health information via physical assessment (clinical history and examination), and investigations (vital signs monitoring, laboratory tests, medical imaging), and further advance the tracking and surveillance of health, enhance decision making at the point of care, trigger the timely detection of clinical deterioration, and better predict surgical outcomes [13,14,18]. While a growing evidence base supports the value of digital phenotyping and PGHD to provide actionable data and targeted interventions, few have comprehensively characterized this technology in surgery or mapped current concepts for driving research and development in this field. The overarching goal of this study was to conduct a rapid scoping review of digital phenotyping and PGHD for outcome measurement in surgery to generate a repository of evidence for the current state of the art, identify knowledge gaps, and guide recommendations for future work.

1.2. Objectives

The primary objective was to map the application of digital phenotyping and digitally captured active and passive PGHD for outcome measurement in surgical care by study characteristics, clinical characteristics, technological/data characteristics, and functional characteristics. The secondary objective was to synthesize the body of evidence to define specific areas of further work necessary to translate this technology from research bench to surgical practice. Ultimately, this review aims to inform stakeholders in advancing the field of patient-centered digital health and outcome measurement in surgical care.
2. Materials and Methods

2.1. Study Design

We performed a rapid scoping review as a streamlined approach to synthesizing evidence for emergent research and development in this field [19–21]. We started with a strategic search applied to multiple electronic databases using search terms related to key concepts within our primary and secondary objectives. This was followed by a stepwise process of screening, data extraction, and synthesis.

2.2. Protocol and Registration

The protocol was developed a priori, guided by the Preferred Reporting Items for Systematic Reviews and Meta-analysis—Extension for Scoping Reviews (PRISMA-ScR) (Appendix A) [20], and study registered prospectively with the Open Science Framework, Center for Open Science (Registration No. url: osf.io/p9c7u).

2.3. Eligibility Criteria

Eligibility criteria were as follows: studies focused on adult patients undergoing any form of surgical care at any phase along the care pathway (i.e., preoperative evaluation, perioperative care, postoperative recovery and rehabilitation), involving personal digital devices used to capture active and/or passive PGHD, describing outcome measurement(s) across any health domain, within original studies (prospective, retrospective, technical feasibility) in peer-reviewed journals that were available in the English language. Studies were excluded if they involved pediatric and adolescent patients, non-surgical contexts, lacked capture of any form of PGHD, involved digital solutions to collect and synthesize PROMs only, or were reviews, commentaries, case studies, without original data, and not available in the English language.

2.4. Search and Data Sources

We developed a search strategy guided by our lead institutional librarian [IV], who is experienced in performing systematic reviews. Following rounds of refinement among the research team we defined and combined terms related to “digital phenotyping and PGHD” (concept A), “outcome measurement” (concept B), and “surgical care” (concept C) (Appendix B). Search engines were selected by consensus among authors and our librarian expert then deployed the final search strategy across the following electronic bibliographic databases: PubMed (NLM), Web of Science (Clarivate Analytics, Philadelphia, PA, USA), Cochrane Library (Wiley, Hoboken, NJ, USA), and IEEE Xplore; Databases were searched on 1 June 2020 and refreshed on 1 July of 2020 to ensure we acquired an up-to-date set of articles before reporting findings. No limits were set in publication dates for search purposes, however results spanned years from 1994 to 2020. Search results were limited by language (English only) and resource type (journal articles only). Search results were exported into and deduplicated with the citation management tool EndNote. The search was supplemented by scanning reference lists of relevant reviews.

2.5. Data Screening

Three investigators (EL/VG/JM) independently screened titles and abstracts from the full set of articles based on eligibility criteria. For quality control and to increase consistency among reviewers, all reviewers initially screened a set of 25 publications at the outset and discussed the results before continuing with the screening process. Subsets of articles from batches were cross-checked by investigators (PJ/EL/VG) for consistency and quality assurance. Excluded studies were coded with reasons for exclusion using the criteria established a priori. Any differences in judgment on inclusion/exclusion of studies were resolved by group discussions with the senior investigator (AH)
as needed. Full-text articles were retrieved for further independent review and final assessment for eligibility (PJ/EU/VG). Number of articles screened, and articles excluded including duplicates were logged for each source of evidence and presented in a PRISMA flow diagram (Appendix C). The final study set for data extraction was thus identified.

2.6. Data Charting Process

Two investigators (PJ/EL) jointly developed the data charting system including electronic forms for screening, data extraction, and synthesis of relevant information (Microsoft Excel, v16.21, USA). The screening form logged articles for inclusion/exclusion, allowed tagging of queried citations for further discussion and recording reasons for excluding articles. The extraction form included parameters developed in relation to our primary objective, i.e., study characteristics, clinical characteristics, technological/data characteristics and functional characteristics. Data items for each category were selected by four investigators (PJ/EL/VG/JM) who charted data independently. These investigators regrouped at regular points throughout the screening and extraction phase to discuss and iterate the data charting parameters. Any inconsistencies were resolved by additional input from the senior author (AH) as needed.

2.7. Data Items and Extraction

We finally abstracted data from the full text (PDFs) of the final set of selected articles on: study characteristics (lead author, study year, country of origin, study design, total number of patients), clinical characteristics (surgical specialty, surgical procedure, point of application along care pathway), technological and data characteristics (type of device including brand/proprietary names, type of data), and functional characteristics (types of clinical function and utility) with additional notes to document salient points.

2.8. Appraisal of Individual Sources of Evidence

We focused on presenting the results as a “map” of data utilizing data visualizations and data tabulations along with a descriptive narrative as per published guidelines, in keeping with a broad and scoping systematic review [20,22]. While we closely reviewed the full text articles during the data extraction phase, we did not proceed with a formal critical appraisal partly given the heterogeneity of the study set (varying study designs in particular), and partly due to the lack of a universal and validated quality assessment tool.

2.9. Synthesis of Results

We synthesized results using coding and grouping of relevant data elements using our electronic database. with descriptive analysis using frequencies and percentages within each category of extracted data. Following consensus discussions on metrics of interest by three investigators [PJ/EL/VG], we proceeded to tabulate data and generate visualizations using a data analytics package (Tableau, 2020. v3.0, Mountain View, CA, USA). Visualizations included a geographical chart of country of origin for selected articles; bubble charts and other standard charts for other metrics of relevance, and a Sankey-type flow diagram (@SankeyMATIC, Virginia, USA) to provide an overview of the specific inter-relation between technological, data and functional characteristics.

3. Results

3.1. Initial Evaluation and Selection of Studies

A total of 3001 citations were generated from the original literature search and after adjusting for duplicates (n = 575), 2426 remained for screening. After reviewing titles and abstracts, 2157 were excluded by criteria leaving 269 publications for full-text review. A further 45 studies were excluded
based on a lack of alignment with our study objectives and leaving a final set of 224 articles (Table 1) (Figure 1) (Appendix B).

**Table 1.** Summary of number of publications within country, surgical specialty, pathway phase, data type, and function categories.

| Category                          | Number of Publications |
|-----------------------------------|------------------------|
| Records identified through database searching (n=3801) |                         |
| Additional records identified through other sources (n = 0) |                         |
| Records after duplicates removed (n = 2426) |                         |
| Records screened (n = 2426) |                         |
| Records excluded (n = 2137) |                         |
| Full-text articles assessed for eligibility (n = 269) |                         |
| Full-text articles excluded, with reasons (n = 45) |                         |
| Studies included in qualitative synthesis (n = 224) |                         |
| Studies included in quantitative synthesis (meta-analysis) (n = 0) |                         |

**Figure 1.** PRISMA Flow Diagram of study identification, screening, eligibility, and inclusion in final review.

From: Moher D, Liberati A, Tetzlaff J, Altman DG. The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed.1000097

For more information, visit [www.prisma-statement.org](http://www.prisma-statement.org).
Table 1. Summary of number of publications within country, surgical specialty, pathway phase, data type, and function categories.

| Category               | Number of Publications |
|------------------------|------------------------|
| **Country**            |                        |
| USA                    | 74                     |
| UK                     | 23                     |
| Netherlands            | 21                     |
| Australia              | 17                     |
| Germany                | 14                     |
| Switzerland            | 10                     |
| Canada                 | 7                      |
| Spain                  | 7                      |
| Japan                  | 6                      |
| Italy                  | 5                      |
| South Korea            | 5                      |
| Belgium                | 4                      |
| Norway                 | 4                      |
| Sweden                 | 4                      |
| Brazil                 | 3                      |
| Denmark                | 3                      |
| Taiwan                 | 3                      |
| China                  | 2                      |
| Greece                 | 2                      |
| Finland                | 1                      |
| France                 | 1                      |
| Israel                 | 1                      |
| Portugal               | 1                      |
| Romania                | 1                      |
| Serbia                 | 1                      |
| South Africa           | 1                      |
| Thailand               | 1                      |
| Turkey                 | 1                      |
| Ukraine                | 1                      |
| **Surgical Specialty** |                        |
| Bariatric              | 10                     |
| Breast                 | 1                      |
| Cardiotoracic          | 15                     |
| Colorectal             | 2                      |
| General                | 13                     |
| Neurosurgery           | 24                     |
| Obstetrics/Gynecology  | 2                      |
| Ophthalmology          | 3                      |
| Oromaxillofacial       | 6                      |
| Orthopaedics           | 129                    |
| Surgical Oncology      | 11                     |
| Transplant             | 7                      |
| Urologic               | 1                      |
| Vascular               | 4                      |
| **Pathway Phase**      |                        |
| Post                   | 171                    |
| Peri                   | 4                      |
| Pre, Post              | 36                     |
| Pre, Peri, Post        | 2                      |
| Peri, Post             | 1                      |
| Pre                    | 10                     |
| **Data Type**          |                        |
| Activity               | 122                    |
| Biometrics             | 59                     |
| Communication          | 0                      |
| Activity, Biometrics   | 41                     |
| Activity, Communication| 2                      |
Table 1. Cont.

| Category | Number of Publications |
|----------|------------------------|
| Feasibility | 61 |
| Tracking or Monitoring | 82 |
| Prediction | 18 |
| Risk Profiling | 8 |
| Optimization | 18 |
| Feasibility, Tracking or Monitoring | 10 |
| Feasibility, Prediction | 1 |
| Feasibility, Risk Profiling, Prediction | 1 |
| Feasibility, Tracking or Monitoring, Prediction | 3 |
| Feasibility, Tracking or Monitoring, Risk Profiling | 2 |
| Risk Profiling, Prediction | 1 |
| Risk Profiling, Prediction, Optimization | 1 |
| Tracking or Monitoring, Optimization | 5 |
| Tracking or Monitoring, Prediction | 6 |
| Tracking or Monitoring, Risk Profiling | 5 |
| Tracking or Monitoring, Risk Profiling, Optimization | 1 |
| Tracking or Monitoring, Risk Profiling, Prediction | 1 |

3.2. Study Characteristics

The number of studies increased over time (Figure 2). Studies originated from 29 countries with the majority performed in the USA (n = 74, 33%) (Figure 3). The majority of studies featured original prospective work (n = 149, 67%), and a substantial proportion of studies involved technical validation and feasibility of digital solutions (n = 50, 22%) (Figure 4). The cohorts of patients involved in these studies ranged from 5 to 406 participants.

Figure 2. Total number of publications by year for studies related to digital phenotyping and patient-generated health data for outcome measurement in surgical care.
3.3. Clinical Characteristics

Studies spanned 14 surgical specialties with the majority being performed in the context of orthopedic surgery (n = 129, 58%) and procedures including total joint replacement, fracture and soft tissue trauma reconstruction, joint fusion, brachial plexus injury, rotator cuff repair, anterior cruciate ligament reconstruction and carpal tunnel release (Figure 5) (Appendix D). The majority of studies were conducted in the postoperative phase (n = 210, 94%).
3.4. Technological/Data Characteristics

Overall, the majority of studies involved research-grade wearables (i.e., non-commercially available wearable sensors/sensors for research purposes only) \((n = 129, 58\%)\), and consumer-grade wearables (i.e., commercially available wearable sensors produced for the consumer market but used for scientific evaluation) \((n = 78, 35\%)\) over smartphone \((n = 15, 7\%)\) or other devices \((n = 6, 3\%)\). There was a predominant focus on capturing activity \((n = 165, 74\%)\), and biometric data \((n = 100, 45\%)\), as opposed to communications data \((n = 2, 1\%)\) (Figure 6). As a single publication could fall under multiple technological or data characteristic categories, the summed percentages are greater than 100%.

The width of each flow is proportional to number of studies channeled from one category to another, i.e., the flow of number of articles published by technology type that involved the capture of activity, biometric and/or communications data in order to provide a given function

3.5. Functional Characteristics

The focus of the majority of studies was on tracking/monitoring of surgical patients \((n = 115, 51\%)\), and assessment of technical feasibility \((n = 78, 35\%)\), versus prediction of surgical outcomes \((n = 32, 14\%)\), risk profiling \((n = 20, 9\%)\), and surgical optimization \((n = 25, 11\%)\). A wide range of technologies were utilized such as activity trackers, smartphone applications, research- and commercial-grade wearables, and other sensors (Appendix E) alongside numerous types of activity, biometric, and communication-related data points (Figure 7). As a single publication could be categorized in multiple functional characteristics, the sum of the values and sum of percentages is higher than 224 and 100%, respectively.

Notably, various patient-reported outcome measures were utilized in more than half of the studies \((n = 121, 54\%)\) and mostly used to validate wearable data. Findings from these evaluations, such as those assessing correlation between data types, were highly variable. PROMs in these studies included measures of condition-specific health (e.g., Hip Disability and Osteoarthritis Outcome Score, HOOS) \((n = 86, 71\%)\), general health and quality of life (e.g., Patient Reported Outcome Measurement Information System (PROMIS)-Global, RAND 36-Item Short Form Health Survey) \((n = 54, 45\%)\),

Figure 5. Area chart representing number of studies by surgical specialty. Studies spanned a total of 14 surgical specialties.
and psychosocial factors (e.g., PHQ-9) \( n = 6, 5\% \). A single publication could utilize more than one PROM; thus, the values are higher than the total 121 of publications.

**Figure 6.** A Sankey-type flow diagram representing flow of studies by technology, data and function.

**Figure 7.** The “Activity-Biometrics-Communication” Framework of Activity, Biometric, and Communications data points captured using Personal Digital Devices. This does not include capture of patient-reported outcome measurements (PROMs) and other survey questions via Smartphone applications/other devices.
4. Discussion

Digital phenotyping and PGHD has been studied in a range of surgical contexts. Smartphones and wearable sensors have been used to capture an array of activity/mobility, biometric, and communication-related data. Studies have been conducted to establish the feasibility of these technologies to gather information from patients, while also assessing the potential for clinically meaningful functions, such as tracking and monitoring change in health status, decision support, and prediction of health outcomes. Our findings should be considered in light of some limitations.

4.1. Limitations

Firstly, scoping reviews encompassing broad concepts that generate large numbers of citations may be prone to human error where investigators inadvertently miss relevant articles. Further, where there are multiple investigators performing screening, there is a risk of alternative interpretations of abstracts. To mitigate this, we commenced screening following independent review and group discussion of a common set of articles, before proceeding with screening in batches and regular check-ins to query any concerns, share ideas, reach consensus, and resolve any disputes as necessary. Second, for speed, only two investigators were involved in developing the initial data charting system. A wider group discussion could have generated additional elements for consideration at the outset. Nevertheless, ample opportunities were built into our process for implementing ideas, new concepts, and iterating the data extraction chart. Third, given the heterogeneity of the articles and intention to encompass studies focused on technical feasibility as well as original research, it was challenging to identify a universal tool to appraise the quality and validity of the studies. Finally, while we aimed to comprehensively categorize the wide variety of devices among these studies, as none of the investigators were technologists, there may have been some degree of error in taxonomy and classification, especially among the commercial- and research-grade wearable/sensors. This may have been further complicated by the proprietary names for the devices which could have varied by geographical region or changed as technologies evolved.

Through the process of our full-text review, we identified three spheres of insights: clinical, technological/data, and interpersonal spheres, with future scopes of work required to realize the translation of personalized digital technologies from the research bench to surgical care [10].

4.2. Clinical Sphere

Authors have categorized surgical applications of wearable technologies into providing augmentative functions (the provision of information in real time for surgeons during clinical or surgical encounters, e.g., head-up displays on glasses), assistive functions (the use of wearables to replace physical tasks, e.g., gesture control of electronic systems while scrubbed for surgery), and assessment functions (i.e., objective measurement of clinical outcomes and disease severity, e.g., tracking mobility data and walking tolerance in degenerative musculoskeletal conditions) [23]. Wearable technologies can overlap to varying extents among these functions and be positioned at differing points along the continuum of surgical centeredness versus patient centeredness [23].

In this scoping review, beyond studies demonstrating technical feasibility alone, most studies involved the assessment function—commonly tracking and monitoring of activity and biometric data. Fewer studies involved prediction, risk profiling, surgical optimization, diagnostic processes, development of new interventions and care delivery models, shared decision making, decision support and targeted treatment selection, and recovery and rehabilitation support, e.g., gamification [24]. Personal digital technologies capturing PGHD were most commonly applied in the context of orthopaedics and neurosurgery. Applications mostly involved wearable motion sensors in populations with chronic musculoskeletal conditions, such as advanced osteoarthritis requiring total joint replacement [25–28]. In the context of musculoskeletal health in general, activity/mobility data (from accelerometers and GPS), communication data (text and telephone logs, screen time),
and self-reported pain (phone-based visual analogue surveys) have been used to predict outcomes of care for spinal conditions [29]. Further, mobility metrics (gait speed using accelerometer and gyroscope sensors) from wearable sensors have been associated with health outcomes, including activities of daily life in older adults [30].

Beyond surgery, the concept of digital phenotyping has been extensively applied in the mental health arena for objective continuous generation of data points representing activities, cognitions, and behaviors (e.g., self-evaluated mood, daily steps, call durations, text frequency, psychosocial PROMs) in the management of conditions including depression, anxiety, bipolar disease, schizophrenia and monitoring suicidal risk [31–45].

Digital phenotyping has also captured recovery metrics and physical activity in non-operative spinal care [18], augmented neurological care [46,47], signaled cardiovascular risk [48], characterized loneliness and social isolation [48], and been used to develop behavioral change interventions [49]. In relation to the point of application along the surgical pathway, personal digital devices have established baseline function [50–52], enabled advanced monitoring of biometric data during the perioperative phase/acute recovery phase [53], and tracked progress during postoperative recovery [24].

**Future Scope**

While there are a wide range of clinical applications, directions for further work and surgical use cases involving digital phenotyping can be summarized as (i) enhanced recovery monitoring, (ii) improving decision making, and (iii) surgical optimization (including optimization/prehabilitation). Further studies are also needed to understand the ability of PGHD to segment patient populations during the care cycle without stigmatizing the individual, define postoperative recovery trajectories, and assess the association of passive PGHD with PROMs.

As PGHD commonly involves activity-related metrics, there seems a natural opportunity to expand this form of measurement in orthopaedics to assess the association with PROMs capturing physical function, especially considering the direct impact of common conditions, such as osteoarthritis and fractures, and interventions, such as total joint replacement surgery and fracture fixation, on physical activities and mobility.

In relation to psychometric evaluation (i.e., assessment of validity, reliability, responsiveness, reproducibility, feasibility and user-friendliness), the same level of rigor applied to testing PROMs should be applied to passive PGHD. Full scale adoption of this technology across different surgical settings also requires forecasting of barriers and pitfalls related to surgical quality and safety, alongside the ethical, privacy, and legal considerations related to the use of this technology [18,54].

**4.3. Technological/Data Sphere**

Personal digital technologies such as smartphones—mobile devices used for core phone functions (voice calls, text messaging) and computing functions (wider software, internet, e.g., web browsing, mobile broadband, and multi-media functionality, e.g., gaming, music, video, cameras)—and wearable sensors (wearables)—small electronic devices embedded into items possessing computational ability that interface with the body—are now ubiquitous across the consumer market [3,23].

We categorized the technologies in this review into smartphone (e.g., Apple iPhone algorithm), consumer-grade wearables (e.g., Fitbit, Apple Watch, Garmin, Microsoft Band, Samsung Gear, Xiaomi MiBand, Huawei Band), and research-grade wearables and sensors (e.g., SenseWear Armband, ActivPal Monitors, Stepwatch Activity Monitor, DynaPort ADL monitor, ActiGraph GT3x Activity Monitor). There were no studies involving sensors embedded into other personal items, e.g., clothing, accessories such as contact lenses, in this review [3,23].

A rapidly evolving combination of sensors, displays, processors and storage memory, and interconnected software and computer algorithms are accelerating the collection, filtering, processing, interpretation, and visualization of an individual’s interactions with their environment from raw data [23]. In this review, we map an array of these generated data points and categorize
them into an “Activity-Biometrics-Communication framework of digital biomarkers” from personal digital devices (Figure 6). The fast pace of this evolution is being fueled by developments in advanced technologies such as artificial intelligence and machine learning (especially around anomaly detection), increasing analytic capabilities alongside advances in collection and processing power. Increase in technical development has been matched by the explosion of scientific work in this field over the last twenty years. This growth may in part be due to the fast-paced release of wearable technologies in the health and fitness consumer market: FitBit releasing their first activity tracker and wearable technologies in 2014; Apple releasing the AppleWatch in 2015; and Garmin releasing the Forerunner 101 back in 2003.

Interestingly, the majority of studies in this review utilized research-grade technologies, despite most of the development, distribution, and sales occurring in the commercial sector. This raises questions around the availability, translation, and scalability of technologies developed and tested at the research bench, and whether such devices serve as appropriate benchmarks for testing commercial-grade devices. In contrast, the proprietary nature of the technology behind commercial-grade devices also warrants further discussion around standardization and scalability. How can health care professionals be sure that the summary statistics from different devices are measuring the same health domain?

The heterogeneity throughout PGHD methodology provides a major challenge for scaling solutions.

Future Scope

Further work is needed around a data infrastructure and defining platforms necessary to support multiple forms of PGHD. The development of Fast Healthcare Interoperability Resources (FHIR), smart marker capabilities, and application programming interfaces (APIs) by the clinical informatics community should support the interoperability of personal digital technologies and applications in existing IT infrastructures as they become standardized within care pathways.

Infrastructure also depends on standardization of this technology, including the validation, testing, refinement, and standardizing the algorithms behind personal digital devices. The issue of standardization is particularly relevant when considering health domains derived from proprietary mathematical models, such as sleep quality. Greater clarity is needed around whether the raw data aligns with the processed data and whether these metrics are measuring what they claim to represent.

Validation of this technology should also include active PGHD, such as PROMs, and understanding the extent to which patient-reported outcomes can and/or should be used as comparators and benchmarks for passive PGHD. Extensive cycles of testing are needed to establish whether passive PGHD from personal digital devices can one day be used as standalone measures of health outcomes or be used side by side with active measurements.

Robust and transparent set of IT governance standards are required to optimize interoperability and reproducibility. In a broader sense, a strategic approach is needed to contend with the rate of technological advancement versus rate of adoption in existing health care settings. Further work should also evaluate the challenges around distribution, access to technology and costs.

4.4. Interpersonal Sphere

While digital phenotyping provides a rich source of PGHD to support the optimal delivery of surgical care, the nature of data captured using personal digital technologies (e.g., how many texts they wrote or how long they spent talking to friends and family; how long they took in moving from place to place); may further humanize the interaction between patients and clinicians [11,12,55]. This interaction contrasts with legacy electronic health record (EHR) systems and systems actively collecting PROMs (via in-person, digital and telephone assessment), that have led to patient and physician burden, burnout, inefficiencies, and distance between patients and providers.

A key aspect of humanizing the technology behind digital phenotyping requires an exploration of patient and professional perspectives around its acceptability, including sensitives and stigmas that may be associated with this form of data. Further, we need to understand how patients and
professionals think and act in response to active and passive data capture, feedback, and visualization of metrics in relation to an individual's condition. Interestingly, early work assessing personal digital data in the mental health arena has shown most patients (in outpatient settings) are happy to share social media and passive smartphone data [20,56]. In contrast, authors have also shown populations have been very apprehensive about actively reporting data summaries from their wearables with concerns around data privacy [18,57].

Future Scope

Further work is needed in surgical settings around the willingness of patients to have their personal passive data shared and utilized for their care [56]. Studies should also investigate the influence of this exposure on performance metrics and outcomes, as well as the way this data shapes the relationship with clinicians [15,58]. The aspect of data overload and data fatigue for clinicians should also be explored. When it comes to multi-disciplinary care and care spanning primary and secondary care, we should aim to define ownership and responsibility for the data.

The successful adoption of digital phenotyping requires an interdisciplinary approach involving co-collaboration and co-development of innovations between stakeholders in health care and digital health (patients and families, health care professionals, medical device industry, researchers, designers, technologists, bioengineers and scientists).

Future work should also explore considerations for integrating PGHD and digital phenotyping into existing patient pathways within and outside the walls of hospitals and clinics. The minimum level of technology required to integrate this technology should be defined alongside an understanding of the relative advantages of data generated for health systems at the clinical, institutional, network, and policy level.

5. Conclusions

Widescale adoption and use of smartphone and wearable technologies in the consumer and surgical health care sector has sparked opportunities to provide a digital phenotype for patients that aims to reflect their physical ability, cognition, social interaction and behavior in free-living settings. Active and passive data generated from sensors within these devices provide a nuanced view of patient outcomes for surgical conditions both alone and in combination with other data elements. While the ubiquity of such personal digital devices across society averts the need to introduce further technology, substantial further work is needed in relation to technological (data collection and analysis), clinical (standardized integration into workflows) and interpersonal (impact on patient–professional relationship) spheres of research and development. As technological, clinical, and interpersonal considerations unfold in this fast-moving space, more sophisticated ways of modelling themes, such as natural language processing of scientific and technical resources, can be used to better understand these elements [59,60]. Digital phenotyping offers an advanced understanding of human behavior and promises to drive objective, scalable, time sensitive, cost-effective, and reproducible digital outcome measurement for improving routine surgical care.

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Conflicts of Interest: The authors declare no conflict of interest.
### Appendix A

Table A1. PRISMA-Scoping Review (ScR) Checklist Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist.

| SECTION | ITEM | PRISMA-ScR CHECKLIST ITEM | REPORTED ON PAGE |
|---------|------|---------------------------|-----------------|
| **TITLE** | | | |
| Title | 1 | Identify the report as a scoping review. | 1 |
| **ABSTRACT** | | | |
| Structured summary | 2 | Provide a structured summary that includes (as applicable): background, objectives, eligibility criteria, sources of evidence, charting methods, results, and conclusions that relate to the review questions and objectives. | 2 |
| **INTRODUCTION** | | | |
| Rationale | 3 | Describe the rationale for the review in the context of what is already known. Explain why the review questions/objectives lend themselves to a scoping review approach. | 3 |
| Objectives | 4 | Provide an explicit statement of the questions and objectives being addressed with reference to their key elements (e.g., population or participants, concepts, and context) or other relevant key elements used to conceptualize the review questions and/or objectives. | 3 |
| **METHODS** | | | |
| Protocol and registration | 5 | Indicate whether a review protocol exists; state if and where it can be accessed (e.g., a Web address); and if available, provide registration information, including the registration number. | 4 |
| Eligibility criteria | 6 | Specify characteristics of the sources of evidence used as eligibility criteria (e.g., years considered, language, and publication status), and provide a rationale. | 4 |
| Information sources | 7 | Describe all information sources in the search (e.g., databases with dates of coverage and contact with authors to identify additional sources), as well as the date the most recent search was executed. | 4 |
| Search | 8 | Present the full electronic search strategy for at least one database, including any limits used, such that it could be repeated. | 4; Appendix B |
| Selection of sources of evidence | 9 | State the process for selecting sources of evidence (i.e., screening and eligibility) included in the scoping review. | 4 |
| Data charting process | 10 | Describe the methods of charting data from the included sources of evidence (e.g., calibrated forms or forms that have been tested by the team before their use, and whether data charting was done independently or in duplicate) and any processes for obtaining and confirming data from investigators. | 5 |
| Data items | 11 | List and define all variables for which data were sought and any assumptions and simplifications made. | 5 |
### Table A1. Cont.

| SECTION                                      | ITEM | PRISMA-ScR CHECKLIST ITEM | REPORTED ON PAGE |
|----------------------------------------------|------|---------------------------|------------------|
| Critical appraisal of individual sources of evidence | 12   | If done, provide a rationale for conducting a critical appraisal of included sources of evidence; describe the methods used and how this information was used in any data synthesis (if appropriate). | n/a; Comment on page 5. |
| Synthesis of results                         | 13   | Describe the methods of handling and summarizing the data that were charted. | 6 |

#### RESULTS

| Selection of sources of evidence            | 14   | Give numbers of sources of evidence screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally using a flow diagram. | 6 |
| Characteristics of sources of evidence     | 15   | For each source of evidence, present characteristics for which data were charted and provide the citations. | 6 |
| Critical appraisal within sources of evidence | 16   | If done, present data on critical appraisal of included sources of evidence (see item 12). | n/a |
| Results of individual sources of evidence  | 17   | For each included source of evidence, present the relevant data that were charted that relate to the review questions and objectives. | 6,7 |
| Synthesis of results                       | 18   | Summarize and/or present the charting results as they relate to the review questions and objectives. | 6,7 |

#### DISCUSSION

| Summary of evidence                        | 19   | Summarize the main results (including an overview of concepts, themes, and types of evidence available), link to the review questions and objectives, and consider the relevance to key groups. | 7–11 |
| Limitations                                | 20   | Discuss the limitations of the scoping review process. | 7 |
| Conclusions                                | 21   | Provide a general interpretation of the results with respect to the review questions and objectives, as well as potential implications and/or next steps. | 11 |

#### FUNDING

| Funding                                    | 22   | Describe sources of funding for the included sources of evidence, as well as sources of funding for the scoping review. Describe the role of the funders of the scoping review. | 11 |

JBI = Joanna Briggs Institute; PRISMA-ScR = Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews.

### Appendix B

Appendix B. Search strategy for PubMed involving terms related to “digital phenotyping and PGHD” (concept A), “outcome measurement” (concept B), and “surgical care” (concept C) (“Digital phenotyp*”[Title/Abstract] OR “Wearable device*”[Title/Abstract] OR “Wearable motion sensor*”[Title/Abstract] OR “Wearable motion sensor*”[Title/Abstract] OR “Wearable motion sensing”[Title/Abstract] OR “Wearable sensor*”[Title/Abstract] OR “Wearable camera*”[Title/Abstract] OR “Wearable technolog*”[Title/Abstract] OR “Wearable electronic device*”[Title/Abstract] OR “Wearable activity monitor*”[Title/Abstract] OR “Wearable activity track*”[Title/Abstract] OR “Wearable activity device*”[Title/Abstract] OR “Wearablesensor technolog*”[Title/Abstract] OR “Wearable
AND

("Outcome Assessment, Health Care"[Mesh] OR "Patient Outcome Assessment"[Mesh] OR "Patient Reported Outcome Measures"[Mesh] OR "Patient Satisfaction"[Mesh] OR "Program Evaluation"[Mesh] OR "Process Assessment, Health Care"[Mesh] OR "Outcome and Process Assessment, Health Care"[Mesh] OR "Treatment Outcome"[Mesh] OR "Recovery of Function"[Mesh] OR "Patient Readmission"[Mesh] OR "Patient Discharge"[Mesh] OR "Self Care"[Mesh] OR "Patient Compliance"[Mesh] OR "Medication Adherence"[Mesh] OR "Quality of Life"[Mesh] OR "Fatal Outcome"[Mesh] OR "Activities of Daily Living"[Mesh] OR "Patient Acceptance of Health Care"[Mesh] OR "Treatment Adherence and Compliance"[Mesh] OR "Treatment Refusal"[Mesh] OR Outcome[Title/Abstract] OR outcomes[Title/Abstract] OR "Patient experience"[Title/Abstract] OR "Patient satisfaction"[Title/Abstract] OR "Patient expectation"[Title/Abstract] OR "Patient expectations"[Title/Abstract] OR "Process evaluation"[Title/Abstract] OR "Process assessment"[Title/Abstract] OR "Process measure"[Title/Abstract] OR "Process measurement"[Title/Abstract] OR "Program evaluation"[Title/Abstract] OR "Program assessment"[Title/Abstract] OR "Patient reported experience"[Title/Abstract] OR "Impact on patient"[Title/Abstract] OR "Surgical outcome"[Title/Abstract] OR "surgical outcomes"[Title/Abstract] OR "Financial cost"[Title/Abstract] OR "Economic impact"[Title/Abstract] OR "Economics"[Title/Abstract] OR "costs"[Title/Abstract] OR "Healthcare cost"[Title/Abstract] OR "Length of stay"[Title/Abstract] OR "Patient discharge"[Title/Abstract] OR "Complications"[Title/Abstract] OR "Readmission"[Title/Abstract] OR "readmissions"[Title/Abstract] OR "Emergency department visit"[Title/Abstract] OR "ED visit"[Title/Abstract] OR "Postoperative hospital visit"[Title/Abstract] OR "Postoperative care"[Title/Abstract] OR "Recovery"[Title/Abstract] OR "Self-management"[Title/Abstract] OR "Self-care"[Title/Abstract] OR "Treatment adherence"[Title/Abstract] OR "Medication adherence"[Title/Abstract] OR "Non-adherence"[Title/Abstract] OR "Follow-up visit"[Title/Abstract] OR "Post-surgical visit"[Title/Abstract] OR "Compliance"[Title/Abstract] OR "Non-compliance"[Title/Abstract] OR "Fear"[Title/Abstract] OR "Quality of life"[Title/Abstract] OR "Clinical effectiveness"[Title/Abstract] OR "Treatment effectiveness"[Title/Abstract] OR "Treatment efficacy"[Title/Abstract] OR "Clinical efficacy"[Title/Abstract] OR "Activities of Daily Living"[Title/Abstract])
OR Paracentesis[Title/Abstract] OR Parathyroidectomy[Title/Abstract] OR "Pelvic Exenteration”[Title/Abstract] OR Phacoemulsification[Title/Abstract] OR Pharyngectomy[Title/Abstract] OR Pharyngostomy[Title/Abstract] OR Photopheresis[Title/Abstract] OR Piezosurgery[Title/Abstract] OR Pinealectomy[Title/Abstract] OR Pneumonectomy[Title/Abstract] OR Portoenterostomy[Title/Abstract] OR Proctectomy [Title/Abstract] OR Psychosurgery[Title/Abstract] OR Pyloromyotomy[Title/Abstract] OR Reconstruction[Title/Abstract] OR Reperfusion[Title/Abstract] OR Replantation[Title/Abstract] OR Resection[Title/Abstract] OR Rhinoplasty[Title/Abstract] OR Salpingostomy[Title/Abstract] OR “Scleral Buckling”[Title/Abstract] OR Scleroplasty[Title/Abstract] OR Sclerostomy[Title/Abstract] OR Shunt[Title/Abstract] OR “Sinus Floor Augmentation”[Title/Abstract] OR Sphincterotomy[Title/Abstract] OR “Spinal Puncture”[Title/Abstract] OR Splenectomy[Title/Abstract] OR “Split-Brain Procedure”[Title/Abstract] OR “Stereotaxic Techniques”[Title/Abstract] OR “Reproductive Sterilization”[Title/Abstract] OR Sternotomy[Title/Abstract] OR Symphysiotomy[Title/Abstract] OR Synovectomy[Title/Abstract] OR Tendon Transfer[Title/Abstract] OR Tenodesis[Title/Abstract] OR Tenotomy[Title/Abstract] OR Thoracoplasty[Title/Abstract] OR Thoracoscopy [Title/Abstract] OR Thoracotomy[Title/Abstract] OR Thymectomy[Title/Abstract] OR Thyroidectomy[Title/Abstract] OR “Tissue Expansion”[Title/Abstract] OR Tonsillectomy[Title/Abstract] OR “Tooth Extraction”[Title/Abstract] OR “Tooth Replantation”[Title/Abstract] OR Tracheostomy[Title/Abstract] OR Tracheotomy[Title/Abstract] OR Trachectomy[Title/Abstract] OR Traction[Title/Abstract] OR Transplant[Title/Abstract] OR Transplantation[Title/Abstract] OR “Ulnar Collateral Ligament Reconstruction”[Title/Abstract] OR Ultrafiltration[Title/Abstract] OR Ureterostomy[Title/Abstract] OR vasectomy[Title/Abstract] OR Vasovasostomy[Title/Abstract] OR Vitrectomy[Title/Abstract] OR “Surgical Procedures, Operative”[Mesh] OR “Surgical Procedures, Operative”[Title/Abstract] OR “Specialties, Surgical”[Mesh] OR “Surgeons”[Mesh])
## Appendix C

**Table A2.** Final Study Set including study characteristics, clinical characteristics, technology/data characteristics and functional characteristics.

| Title                                                                 | Author               | Year | Country | Study Design       | Surgical Specialty | Pathway Phase | Technology Type | Data Type | Function |
|-----------------------------------------------------------------------|----------------------|------|---------|--------------------|--------------------|---------------|----------------|-----------|----------|
| Physical activity monitors can be successfully implemented to assess Perioperative activity in urologic surgery | Agarwal, D. K., et al. | 2018 | USA     | Feasibility/Validity | Urologic           | Pre, Post     | CGW            | Activity  | F        |
| Reliability of Physical Activity Measures During Free-Living Activities in People After Total Knee Arthroplasty | Almeida, G. J., et al. | 2016 | USA     | Feasibility/Validity | Orthopaedics       | Post          | RGW            | Activity  | TM, O    |
| Responsiveness of Physical Activity Measures Following Exercise Programs after Total Knee Arthroplasty | Almeida, G. J., et al. | 2017 | USA     | Feasibility/Validity | Orthopaedics       | Post          | RGW            | Activity  | O        |
| Validity of physical activity measures in individuals after total knee arthroplasty | Almeida, G. J., et al. | 2015 | USA     | Feasibility/Validity | Orthopaedics       | Post          | RGW            | Activity  | F        |
| Kinematic and clinical evaluation of shoulder function after primary and revision reverse shoulder prostheses | Alta, T. D., et al.  | 2011 | Netherlands | Original Prospective | Orthopaedics       | Post          | RGW            | Biometrics | TM       |
| The active and passive kinematic difference between primary reverse and total shoulder prostheses | Alta, T. D., et al.  | 2014 | Netherlands | Original Prospective | Orthopaedics       | Post          | RGW            | Biometrics | O        |
| Long-term clinical evaluation of the automatic stance-phase lock-controlled prosthetic knee joint in young adults with unilateral above-knee Amputation | Andrysek, J., et al. | 2017 | Canada | Original Prospective | Orthopaedics       | Post          | CGW            | Activity, Biometrics | TM       |
| Mobile Phone-Connected Wearable Motion Sensors to Assess Postoperative Mobilization | Appelboom, G., et al. | 2015 | USA     | Original Prospective | Neurosurgery        | Post          | CGW            | Activity  | F        |
| Monitoring activity of hip injury patients (MoHIP): a sub-study of the World Hip Trauma Evaluation observational cohort study | Armitage, L. C., et al. | 2020 | UK      | Original Prospective | Orthopaedics       | Post          | CGW            | Activity  | TM       |
| High Plantar Force Loading After Achilles Tendon Rupture Repair with Early Functional Mobilization | Aufwerber, S., et al. | 2019 | Sweden  | Original Prospective | Orthopaedics       | Post          | CGW            | Activity  | P        |
| Psychological factors are associated with return to Pre-injury levels of sport and physical activity after ACL reconstruction | Baez, S. E., et al.  | 2020 | USA     | Original Prospective | Orthopaedics       | Post          | CGW            | Activity  | TM       |
| Title                                                                 | Author                     | Year  | Country | Study Design  | Surgical Specialty | Pathway Phase | Technology Type | Data Type | Function |
|----------------------------------------------------------------------|----------------------------|-------|---------|---------------|---------------------|---------------|----------------|-----------|----------|
| Feasibility of low-cost accelerometers in measuring functional recovery after major oncologic surgery | Barkley, R., et al. | 2019  | USA     | Feasibility/Validity | Surgical Oncology  | Pre, Post     | CGW            | Activity  | F        |
| Assessment of a SP app (Capstesia) for measuring pulse Pressure variation: agreement between two methods: A Cross-sectional study | Barrachina, B., et al.    | 2017  | Spain   | Feasibility/Validity | General Surgery    | Peri          | SP             | Biometrics | F        |
| Physical Activity, Quality of Life and Body Image of Candidates to Bariatric Surgery | Barreto, B. L. M., et al. | 2018  | Brazil  | Original Prospective | Bariatric          | Post          | CGW            | Activity   | O        |
| Cementless THA for the treatment of osteonecrosis at 10-year follow-up: have we improved compared to cemented THA? | Bedard, N. A., et al.     | 2013  | USA     | Original Prospective | Orthopaedics       | Post          | RGW            | Activity   | TM       |
| Functional outcome analysis of operatively treated malleolar fractures | Belcher, G. L., et al.    | 1997  | USA     | Original Prospective | Orthopaedics       | Post          | CGW            | Activity   | TM       |
| Changes in prospectively collected longitudinal patient-generated health data are associated with short-term patient-reported outcomes after total joint arthroplasty: a pilot study | Bendich, I., et al.       | 2019  | USA     | Original Prospective | Orthopaedics       | Post          | CGW            | Activity   | RP       |
| Activity levels and polyethylene wear of patients 10 years Post hip replacement | Bennett, D., et al.       | 2008  | UK      | Original Cross-sectional | Orthopaedics       | Post          | CGW            | Activity   | RP       |
| Geriatric rehabilitation after hip fracture. Role of body-fixed sensor measurements of physical activity | Benzinger, P., et al.     | 2014  | Germany | Original Cross-sectional | Orthopaedics       | Post          | CGW            | Activity   | F        |
| Postoperative quality-of-life assessment in patients with spine metastases treated with long-segment pedicle-screw fixation | Bernard, F., et al.       | 2017  | France  | Original Retrospective | Neurosurgery       | Post          | CGW            | Activity   | TM       |
| What are the functional outcomes of endoprosthetic reconstructions after tumor resection? | Bernthal, N. M., et al.   | 2015  | USA     | Original Prospective | Surgical Oncology  | Post          | RGW            | Activity, Biometrics | P        |
| Pervasive wearable device for free tissue transfer monitoring based on advanced data analysis: clinical study report | Berthelot, M., et al.     | 2019  | UK      | Original Prospective | Breast             | Peri          | RGW            | Biometrics | F        |
| Machine Learning Algorithms Can Use Wearable Sensor Data to Accurately Predict Six-Week Patient-Reported Outcome Scores Following Joint Replacement in a Prospective Trial | Bini, S. A., et al.       | 2019  | USA     | Original Prospective | Orthopaedics       | Post          | CGW            | Activity, Biometrics | P        |
| Title                                                                 | Author                        | Year | Country     | Study Design     | Surgical Specialty | Pathway Phase | Technology Type | Data Type | Function |
|----------------------------------------------------------------------|-------------------------------|------|-------------|------------------|---------------------|---------------|-----------------|-----------|----------|
| Monitoring of Postoperative Bone Healing Using Smart Trauma-Fixation Device with Integrated Self-Powered Piezo-Floating-Gate Sensors | Borchani, W., et al.          | 2015 | USA         | Feasibility/Validity | Orthopaedics        | Post           | RGW             | Biometrics | F        |
| Cross-sectional assessment of daily physical activity in chronic obstructive Pulmonary disease lung transplant patients | Bossenbroek, L., et al.       | 2009 | Netherlands | Original Cross-sectional | Transplant         | Post           | CGW             | Activity, Biometrics | TM       |
| Changes in physical activity and health-related quality of life during the first year after total knee arthroplasty | Brandes, M., et al.           | 2011 | Germany     | Original Prospective | Orthopaedics        | Pre, Post      | RGW             | Activity, Biometrics | TM       |
| Quantity versus quality of gait and quality of life in patients with osteoarthritis | Brandes, M., et al.           | 2008 | Germany     | Original Prospective | Orthopaedics        | Pre, Post      | RGW             | Activity, Biometrics | F        |
| Impact of a tailored activity counselling intervention during inpatient rehabilitation after knee and hip arthroplasty—an explorative RCT | Brandes, M., et al.           | 2018 | Germany     | Original Prospective | Orthopaedics        | Post           | RGW             | Activity   | O        |
| Reliability of wireless monitoring using a wearable patch sensor in high-risk surgical patients at a step-down unit in the Netherlands: a clinical validation study | Bretelet, M. J. M. M., et al. | 2018 | Netherlands | Original Prospective | General Surgery     | Post           | RGW             | Activity, Biometrics | F        |
| Are current wireless monitoring systems capable of detecting adverse events in high-risk surgical patients? A descriptive study | Bretelet, M. J. M., et al.     | 2020 | Netherlands | Original Cross-sectional | General Surgery     | Post           | RGW             | Biometrics | F        |
| Vital Signs Monitoring with Wearable Sensors in High-risk Surgical Patients: A Clinical Validation Study | Bretelet, M. J. M., et al.     | 2020 | Netherlands | Original Cross-sectional | General Surgery     | Post           | RGW             | Biometrics | TM       |
| Novel positioning sensor with real-time feedback for improved Postoperative positioning: pilot study in control subjects | Brodie, F. L., et al.         | 2017 | USA         | Original Prospective | Ophthalmology       | Peri           | CGW             | Biometrics | F        |
| Validity and reliability of measurements obtained with an "activity monitor" in people with and without a transtibial Amputation | Bussmann, H. B., et al.       | 1998 | Netherlands | Feasibility/Validity | Orthopaedics        | Post           | RGW             | Activity, Biometrics | F        |
| Title                                                                 | Author                        | Year | Country      | Study Design         | Surgical Specialty | Pathway Phase | Technology Type | Data Type     | Function |
|---------------------------------------------------------------------|-------------------------------|------|--------------|----------------------|--------------------|---------------|----------------|---------------|----------|
| Validity of the prosthetic activity monitor to assess the duration and spatio-temporal characteristics of prosthetic walking | Bussmann, J. B., et al.       | 2004 | Netherlands  | Feasibility/Validity | Orthopaedics       | Post          | RGW            | Biometrics    | F        |
| Ambulatory accelerometry to quantify motor behaviour in patients after failed back surgery: a validation study | Bussmann, J. B., et al.       | 1998 | Netherlands  | Feasibility/Validity | Neurosurgery       | Post          | RGW            | Activity, Biometrics | F        |
| Inertial Sensor-Based Gait and Attractor Analysis as Clinical Measurement Tool: Functionality and Sensitivity in Healthy Subjects and Patients with Symptomatic Lumbar Spinal Stenosis | Byrnes, S. K., et al.         | 2018 | Switzerland  | Feasibility/Validity | Neurosurgery       | Post          | RGW            | Biometrics    | O        |
| Cardiac Surgery Rehabilitation System (CSRS) for a Personalized Support to Patients | Caggianese, G., et al.        | 2017 | Italy        | Original Prospective | Cardiothoracic     | Post          | CGW            | Activity      | TM       |
| Clinical evaluation of a mobile sensor-based gait analysis method for outcome measurement after knee arthroplasty | Calliess, T., et al.          | 2014 | Germany      | Feasibility/Validity | Orthopaedics       | Pre, Post      | RGW            | Activity, Biometrics | F        |
| Higher pyruvate levels after Achilles tendon rupture surgery could be used as a prognostic biomarker of an improved patient outcome | Capone, G., et al.            | 2020 | Sweden       | Original Prospective | Orthopaedics       | Post          | CGW            | Activity      | P        |
| Wearable Technology-A Pilot Study to Define “Normal” Postoperative Recovery Trajectories | Carmichael, H., et al.       | 2019 | USA          | Original Prospective | General Surgery    | Pre, Post      | CGW            | Activity      | TM       |
| Patterns of physical activity and sedentary behavior after Bariatric: an observational study | Chapman, N., et al.          | 2014 | Australia    | Original Prospective | Bariatric          | Post          | RGW            | Activity, Biometrics | O        |
| Data Collection and Analysis Using Wearable Sensors for Monitoring Knee Range of Motion after Total Knee Arthroplasty | Chiang, C. Y., et al.        | 2017 | Taiwan       | Original Prospective | Orthopaedics       | Post          | RGW            | Activity      | F        |
| Feasibility and Preliminary Outcomes of a Physical Therapist-Administered Physical Activity Intervention After Total Knee Replacement | Christiansen, M. B., et al.  | 2019 | USA          | Feasibility/Validity | Orthopaedics       | Post          | CGW            | Activity      | F        |
| An Assessment of Physical Activity Data Collected via a Smartphone App and a Smart Band in Breast Cancer Survivors: Observational Study | Chung, I. Y., et al.         | 2019 | South Korea  | Original Prospective | Surgical Oncology  | Post          | SP, CGW        | Activity, Biometrics | F        |
Table A2. Cont.

| Title | Author | Year | Country | Study Design | Surgical Specialty | Pathway Phase | Technology Type | Data Type | Function |
|---|---|---|---|---|---|---|---|---|---|
| Inertial sensor-based measures of gait symmetry and repeatability in people with unilateral lower limb amputation | Clemens, S., et al. | 2020 | USA | Original Prospective | Orthopaedics | Post | RGW | Activity | TM |
| Use of a wrist-mounted device for continuous outpatient physiologic monitoring after transsphenoidal surgery: a pilot study | Cole, T. S., et al. | 2019 | USA | Original Prospective | Oromaxillofacial | Post | CGW | Activity, Biometrics | F |
| Understanding the Capacity for Exercise in Post-Bariatric Patients | Coleman, K. J., et al. | 2017 | USA | Original Prospective | Bariatric | Post | CGW | Activity | F, TM |
| A multicomponent intervention to decrease sedentary time during hospitalization: a quasi-experimental pilot study | Conijn, D., et al. | 2020 | Netherlands | Original Prospective | Vascular, Transplantation | Post | CGW | Activity | F |
| Digital Phenotyping in Patients with Spine Disease: A Novel Approach to Quantifying Mobility and Quality of Life | Cote, D. J., et al. | 2019 | USA | Original Prospective | Neurosurgery | Post | SP | Activity, Communication | TM |
| Late effects of a brief psychological intervention in patients with intermittent claudication in a randomized clinical trial | Cunningham, M. A., et al. | 2013 | Australia | Original Prospective | Vascular | Post | Unknown | Activity | P |
| Daily Physical Activity in Total Hip Arthroplasty Patients Undergoing Different Surgical Approaches A Cohort Study | Engdal, M., et al. | 2017 | Norway | Original Prospective | Orthopaedics | Post | RGW | Activity, Biometrics | TM |
| Validation of the Fitbit Flex in an Acute Post-Cardiac Surgery Patient Population | Daligadu, J., et al. | 2018 | Canada | Feasibility/Validity | Cardiothoracic | Post | CGW | Activity | F |
| Association of Wearable Activity Monitors with Assessment of Daily Ambulation and Length of Stay Among Patients Undergoing Major Surgery | Dasikivich, T. J., et al. | 2019 | USA | Original Prospective | Cardiothoracic, General Surgery, Bariatric | Post | CGW | Activity | F |
| Are patients with knee osteoarthritis and patients with knee joint replacement as physically active as healthy persons? | Daugaard, R., et al. | 2018 | Denmark | Original Prospective | Orthopaedics | Post | CGW | Activity | TM |
| Physical Activity Levels During Acute Inpatient Admission After Hip Fracture are Very Low | Davenport, S. J., et al. | 2014 | Australia | Original Cross-sectional | Orthopaedics | Pre, Post | RGW | Activity, Biometrics | TM |
| Feasibility of real-time location systems in monitoring recovery after major abdominal surgery | Dorrell, R. D., et al. | 2017 | USA | Original Prospective | General Surgery | Post | RGW | Activity | TM |
| Title                                                                 | Author                     | Year | Country | Study Design       | Surgical Specialty | Pathway Phase | Technology Type | Data Type | Function |
|----------------------------------------------------------------------|----------------------------|------|---------|--------------------|--------------------|---------------|----------------|-----------|----------|
| Continuous Versus Intermittent Vital Signs Monitoring Using a Wearable, Wireless Patch in Patients Admitted to Surgical Wards: Pilot Cluster Randomized Controlled Trial | Downey, C., et al.         | 2018 | UK      | Feasibility/Validity | General Surgery    | Post          | RGW            | Biometrics | F        |
| Distribution of arm velocity and frequency of arm usage during daily activity: objective outcome evaluation after shoulder surgery | Duc, C., et al.            | 2013 | Switzerland | Feasibility/Validity | Orthopaedics       | Post          | RGW            | Biometrics | TM       |
| Objective evaluation of cervical spine mobility after surgery during free-living activity | Duc, C., et al.            | 2013 | Belgium | Feasibility/Validity | Neurosurgery       | Post          | RGW            | Biometrics | TM       |
| Ambulation monitoring of transtibial Amputation subjects with patient activity monitor versus pedometer | Dudek, N. L., et al.       | 2008 | Canada  | Feasibility/Validity | Orthopaedics       | Post          | CGW            | Activity   | F        |
| Evaluating patients’ walking capacity during hospitalization for lung cancer resection | Esteban, P. A., et al.     | 2017 | Spain   | Original Cross-sectional | Cardiothoracic | Post          | CGW            | Activity   | TM       |
| Activity and socket wear in the Charnley low-friction arthroplasty | Feller, J. A., et al.      | 1994 | Australia | Original Retrospective | Orthopaedics       | Post          | Unknown        | Activity   | TM       |
| Physical activity monitoring: a responsive and meaningful patient-centered outcome for surgery, chemotherapy, or radiotherapy? | Ferriolli, E., et al.      | 2012 | UK      | Original Cross-sectional | General Surgery    | Post          | RGW            | Activity   | F        |
| A feasibility study of an unsupervised, Pre-operative exercise program for adults with lung cancer | Finley, D. J., et al.      | 2020 | USA     | Feasibility/Validity | Cardiothoracic     | Pre            | CGW            | Activity, Biometrics | F        |
| Differences in Preferred walking speeds in a gait laboratory compared with the real world after total hip replacement | Foucher, K. C., et al.     | 2010 | USA     | Original Prospective | Orthopaedics       | Post          | RGW            | Activity   | TM       |
| Pilot study of methods to document quantity and variation of independent patient exercise and activity after total knee arthroplasty | Franklin, P. D., et al.    | 2006 | USA     | Feasibility/Validity | Orthopaedics       | Post          | RGW            | Activity, F, TM |         |
| Improvements in Objectively Measured Activity Behaviors Do Not Correlate with Improvements in Patient-Reported Outcome Measures Following Total Knee Arthroplasty | Frimpong, E., et al.      | 2020 | South Africa | Original Prospective | Orthopaedics       | Pre, Post      | RGW            | Activity   | P        |
| Prospective study of physical activity and quality of life in Japanese women undergoing total hip arthroplasty | Fujita, K., et al.         | 2013 | Japan   | Original Cross-sectional | Orthopaedics       | Pre, Post      | RGW            | Activity   | TM       |
| Title                                                                 | Author                        | Year | Country | Study Design     | Surgical Specialty | Pathway Phase | Technology Type | Data Type | Function       |
|----------------------------------------------------------------------|-------------------------------|------|---------|------------------|---------------------|---------------|-----------------|-----------|----------------|
| Effects of cycle ergometer use in early mobilization following cardiac surgery: a randomized controlled trial | Gama Lordello, G. G., et al.  | 2020 | Brazil  | Original Prospective | Cardiothoracic     | Post           | CGW             | Activity | P              |
| Enhancing patient mobility following cesarean-delivery—the efficacy of an improved Postpartum protocol assessed with pedometers | Ganer Herman, H., et al.      | 2020 | Israel  | Original Prospective | Obstetrics/Gynecology | Post           | CGW             | Activity | P              |
| Assessment and Post-Intervention recovery following surgery for Lumbar Disc Herniation based on objective gait metrics from wearable devices using the Gait Posture index: GPi™ | Ghent, F., et al.             | 2020 | Australia | Feasibility/Validity | Neurosurgery        | Pre, Post      | CGW             | Activity, Biometrics | TM            |
| Physical activity patterns of patients immediately after lumbar surgery | Gilmore, S. J., et al.        | 2019 | Australia | Original Prospective | Neurosurgery        | Post           | RGW             | Activity | P              |
| Assessing the utility of an IoP application in the Perioperative care of spine surgery patients: the NeuroPath Pilot study | Glauser, G., et al.           | 2019 | USA     | Feasibility/Validity | Neurosurgery        | Pre, Post      | SP              | Activity, Communication | F              |
| A Step in the Right Direction: Body Location Determines Activity Tracking Device Accuracy in Total Knee and Hip Arthroplasty Patients | Goel, R., et al.              | 2020 | USA     | Original Prospective | Orthopaedics        | Post           | CGW             | Biometrics | TM            |
| Comparative study of the activity of total hip arthroplasty patients and normal subjects | Goldsmith, A. A., et al.      | 2001 | UK      | Original Prospective | Orthopaedics        | Post           | CGW             | Activity | TM            |
| CAPACITY: A physical activity self-management program for patients undergoing surgery for lung cancer, a phase I feasibility study | Granger, C. L., et al.        | 2018 | Australia | Original Prospective | Cardiothoracic     | Pre, Post      | CGW             | Activity | F              |
| Accelerometry as a measure of modifiable physical activity in high-risk elderly Preoperative patients: a prospective observational pilot study | Grimes, L., et al.           | 2019 | UK      | Original Prospective | General Surgery     | Pre            | CGW             | Activity | F, TM         |
| Does the Femoral Head Size in Hip Arthroplasty Influence Lower Body Movements during Squats, Gait and Stair Walking? A Clinical Pilot Study Based on Wearable Motion Sensors | Grip, H., et al.              | 2019 | Sweden  | Feasibility/Validity | Orthopaedics        | Post           | RGW             | Activity, Biometrics | F              |
| Assessment of objective ambulation in lower extremity sarcoma patients with a continuous activity monitor: rationale and validation | Gundale, K. R., et al.        | 2014 | USA     | Feasibility/Validity | Surgical Oncology   | Post           | RGW             | Activity | F              |
| Title                                                                 | Author                  | Year | Country | Study Design      | Surgical Specialty | Pathway Phase | Technology Type | Data Type | Function |
|----------------------------------------------------------------------|-------------------------|------|---------|-------------------|---------------------|---------------|----------------|-----------|----------|
| Remote Gait Analysis Using Wearable Sensors Detects Asymmetric Gait Patterns in Patients Recovering from ACL Reconstruction | Gurchiek, R. D., et al. | 2019 | USA     | Original Cross-sectional | Orthopaedics      | Post          | RGW            | Biometrics | F        |
| Open-Source Remote Gait Analysis: A Post-Surgery Patient Monitoring Application | Gurchiek, R. D., et al. | 2019 | USA     | Feasibility/Validity | Orthopaedics      | Post          | SP, RGW         | Activity, Biometrics | F        |
| Physical performance and self-report outcomes associated with use of passive, adaptive, and active prosthetic knees in persons with unilateral, transfemoral Amputation: Randomized crossover trial | Hafner, B. J. and R. L. Askew | 2015 | USA     | Original Prospective | Orthopaedics      | Post          | RGW            | Activity   | TM       |
| Using MEMS-based inertial sensor with ankle foot orthosis for telerehabilitation and its clinical evaluation in brain injuries and total knee replacement patients | Han, S. L., et al.      | 2016 | Taiwan  | Feasibility/Validity | Orthopaedics      | Post          | RGW            | Activity   | F        |
| Do activity levels increase after total hip and knee arthroplasty?     | Harding, P., et al.     | 2014 | Australia | Original Prospective | Orthopaedics      | Pre, Post      | RGW            | Activity   | TM       |
| Knee arthroplasty: a cross-sectional study assessing energy expenditure and activity | Hayes, D. A., et al.    | 2011 | Australia | Original Cross-sectional | Orthopaedics | Pre, Post | RGW            | Activity, Biometrics | P        |
| Wearable Technology in the Perioperative Period: Predicting Risk of Postoperative Complications in Patients Undergoing Elective Colorectal | Hedrick, T. L., et al.  | 2020 | USA     | Original Prospective | Colorectal         | Pre, Post      | CGW            | Activity   | RP       |
| Detecting Postural transitions: a robust wavelet-based approach       | Hemmati, S. and E. Wade | 2016 | USA     | Original Prospective | Orthopaedics      | Post          | RGW            | Activity   | F        |
| Low validity of the Sensewear Pro3 activity monitor compared to indirect calorimetry during simulated free living in patients with osteoarthritis of the hip | Hermann, A., et al. (2014). | 2014 | Denmark | Original Cross-sectional | Orthopaedics | Pre, Post | RGW            | Biometrics | F        |
| Clinical outcome and physical activity measured with StepWatch 3 (TM) Activity Monitor after minimally invasive total hip arthroplasty | Holl, S., et al.        | 2018 | Germany | Original Prospective | Orthopaedics      | Pre, Post      | RGW            | Activity   | TM       |
| Interaction between physical activity and continuous-flow left ventricular assist device function in outpatients | Hu, S.X., et al.        | 2013 | Australia | Original Prospective | Cardiothoracic     | Post          | RGW            | Activity, Biometrics | TM, P    |
| 2009 Marshall Urist Young Investigator Award: how often do patients with high-flex total knee arthroplasty use high flexion? | Huddleston, J. I., et al. | 2009 | USA     | Original Cross-sectional | Orthopaedics      | Post          | RGW            | Activity   | TM, P    |
| Title                                                                 | Author                      | Year | Country | Study Design     | Surgical Specialty | Pathway Phase | Technology Type | Data Type       | Function |
|----------------------------------------------------------------------|-----------------------------|------|---------|------------------|---------------------|---------------|-----------------|-----------------|----------|
| Tri-axial accelerometer analysis techniques for evaluating functional use of the extremities | Hurd, W.J., et al.          | 2013 | USA     | Original Prospective | Orthopaedics        | Pre           | RGW             | Activity        | F        |
| Patient-Reported and Objectively Measured Function Before and After Reverse Shoulder Arthroplasty | Hurd, W.J., et al.          | 2018 | USA     | Original Prospective | Orthopaedics        | Post          | RGW             | Activity        | F, TM    |
| A Smart Assistance Solution for Remotely Monitoring the Orthopaedic Rehabilitation Process Using Wearable Technology: re.flex System | Ianculescu, M., et al.      | 2019 | Romania | Feasibility/Validity | Orthopaedics        | Post          | CGW             | Activity        | F        |
| Physical activity patterns and function 3 months after arthroscopic partial meniscectomy | Illch, S.S., et al.         | 2012 | Australia | Original Prospective | Neurosurgery        | Post          | RGW             | Activity        | TM       |
| Objective evaluation of Postoperative changes in real-life activity levels in the Postoperative course of lumbar spinal surgery using wearable trackers | Inoue, M., et al.           | 2020 | Japan   | Original Prospective | Neurosurgery        | Post          | RGW             | Activity        | TM       |
| HipGuard: A Wearable Measurement System for Patients Recovering from a Hip Operation | Iso-Ketola, P., et al.      | 2008 | Finland | Feasibility/Validity | Orthopaedics        | Post          | RGW             | Biometrics      | F        |
| Upright Time and Sit-To-Stand Transition Progression After Total Hip Arthroplasty: An Inhospital Longitudinal Study | Jeldi, A. J., et al.        | 2016 | UK      | Original Prospective | Orthopaedics        | Post          | RGW             | Biometrics      | TM       |
| Metal ion concentrations after metal-on-metal hip arthroplasty are not correlated with habitual physical activity levels | Jelsma, J., et al.          | 2019 | Netherlands | Original Prospective | Orthopaedics        | Post          | RGW             | Activity        | P        |
| Association of Daily Step Count with the Prolonged Air Leak in Thoracic Surgery Patients | Kavurmaci, Ö., et al.       | 2020 | Turkey  | Original Cross-sectional | Cardiothoracic     | Post          | Unknown         | Activity        | P        |
| The Usefulness of a Wearable Device in Daily Physical Activity Monitoring for the Hospitalized Patients Undergoing Lumbar Surgery | Kim, D. H., et al.         | 2019 | South Korea | Original Prospective | Neurosurgery        | Post          | CGW             | Activity, Biometrics | TM, P    |
| Associations between physical activity and mental health among Bariatric surgical candidates | King, W. C., et al.        | 2013 | USA     | Original Cross-sectional | Bariatric          | Pre           | RGW             | Activity        | TM, RP, O |
| Seasonal Variation in Physical Activity among Preoperative Patients with Lung Cancer Determined Using a Wearable Device | Kong, S., et al.           | 2020 | South Korea | Original Cross-sectional | Cardiothoracic     | Pre           | CGW             | Activity        | TM       |
Table A2. Cont.

| Title | Author | Year | Country | Study Design | Surgical Specialty | Pathway Phase | Technology Type | Data Type | Function |
|-------|--------|------|---------|--------------|--------------------|---------------|----------------|-----------|----------|
| Gamified 3D Orthopaedic Rehabilitation using Low Cost and Portable Inertial Sensors | Kontadakis, G., et al. | 2017 | Greece | Feasibility/Validity | Orthopaedics | Post | RGW | Activity | F |
| Relationship Between Physical Activity and Clinical Outcomes After ACL Reconstruction | Kuenze, C., et al. | 2019 | USA | Original Cross-sectional | Orthopaedics | Post | RGW | Activity | F, TM |
| Gait Pattern Recognition Using a Smartwatch Assisting Postoperative Physiotherapy | Kyritsis, A. I., et al. | 2019 | Switzerland | Original Prospective | Orthopaedics | Post | CGW | Biometrics | F |
| Gait Recognition with Smart Devices Assisting Postoperative Rehabilitation in a Clinical Setting | Kyritsis, A. I., et al. | 2018 | Switzerland | Feasibility/Validity | Orthopaedics | Post | CGW | Biometrics | F |
| Recovery of mobility after knee arthroplasty—Expected rates and influencing factors | Lamb, S. E. and H. Frost | 2003 | UK | Original Prospective | Orthopaedics | Post | RGW | Biometrics | TM |
| Physical activity is unrelated to cognitive performance in Pre-Bariatric patients | Langenberg, S., et al. | 2015 | Germany | Original Prospective | Bariatric | Pre | RGW | Activity, Biometrics | RP, P, O |
| Physical activity in daily life 1 year after lung transplantation | Langer, D., et al. | 2009 | Belgium | Original Prospective | Transplant | Post | RGW | Activity, Biometrics | TM |
| Predicting physical activity recovery after hip and knee arthroplasty? A longitudinal cohort study | Lebleu, J., et al. | 2019 | Belgium | Original Cross-sectional | Orthopaedics | Post | CGW | Activity | TM, P |
| iHandU: Towards the Validation of a Wrist Rigidity Estimation for Intraoperative DBS Electrode Position Optimization | Lopes, E. M., et al. | 2019 | Portugal | Feasibility/Validity | Neurosurgery | Peri | RGW | Biometrics | F |
| Adherence to a pedometer-based physical activity intervention following kidney transplant and impact on metabolic parameters | Lorenz, E. C., et al. | 2015 | USA | Original Prospective | Transplant | Post | CGW | Activity | F, TM, P |
| Financial Incentives and Health Coaching to Improve Physical Activity Following Total Knee Replacement: A Randomized Controlled Trial | Losina, E., et al. | 2018 | USA | Original Prospective | Orthopaedics | Post | CGW | Activity | F, TM, P |
| Fitbit step counts during inpatient recovery from cancer surgery as a Predictor of readmission | Low, C. A., et al. | 2017 | USA | Original Prospective | Surgical Oncology | Post | CGW | Activity | TM, RP |
| Is Activity Tracker-Measured Ambulation an Accurate and Reliable Determinant of Postoperative Quality of Recovery? A Prospective Cohort Validation Study | Massouh, F., et al. | 2019 | Canada | Original Prospective | Obstetrics/Gynecology | Post | CGW | Activity | F |
| Title | Author | Year | Country | Study Design | Surgical Specialty | Pathway Phase | Technology Type | Data Type | Function |
|-------|--------|------|---------|--------------|---------------------|---------------|----------------|-----------|----------|
| Relationship between body mass index and activity in hip or knee arthroplasty patients | McClung, C. D., et al. | 2000 | USA | Original Cross-sectional | Orthopaedics | Post | Unknown | Activity | TM, RP |
| Patient-Generated Actigraphy Data as a Novel Outcomes Instrument in Carpal Tunnel Syndrome | McMahon, H. A., et al. | 2020 | USA | Original Prospective | Orthopaedics | Post | RGW | Activity, Biometrics | F |
| Use of the pedometer in the evaluation of the effects of rehabilitation treatment on deambulatory autonomy in patients with lower limb arthroplasty during hospital rehabilitation: long-term Postoperative outcomes | Melchiorri, G., et al. | 2020 | Italy | Original Cross-sectional | Orthopaedics | Post | CGW | Activity | F, TM |
| Physical Function and Pre-Amputation Characteristics Explain Daily Step Count after Dysvascular Amputation | Miller, M. J., et al. | 2019 | USA | Original Cross-sectional | Vascular | Post | RGW | Activity | F, TM, RP |
| Evaluation of respiratory status and mandibular movement after total temporomandibular joint replacement in patients with rheumatoid arthritis | Mishima, K., et al. | 2003 | Japan | Original Prospective | Oromaxillofacial | Pre, Post | RGW | Biometrics | F, TM |
| Real-Time Monitoring of Bone Fracture Recovery by Using Aware, Sensing, Smart, and Active Orthopedic Devices | Mišić, D., et al. | 2018 | Serbia | Feasibility/Validity | Orthopaedics | Post | RGW | Biometrics | F |
| Proposed objective scoring algorithm for assessment and intervention recovery following surgery for lumbar spinal stenosis based on relevant gait metrics from wearable devices: the Gait Posture index (GPI) | Mobbs, R. J., et al. | 2019 | Australia | Feasibility/Validity | Neurosurgery | Post | CGW | Activity, Biometrics | F, RP, P |
| Physical Activity Measured with Accelerometer and Self-Rated Disability in Lumbar Spine Surgery: A Prospective Study | Mobbs, R. J., et al. | 2016 | Australia | Original Prospective | Neurosurgery | Pre, Post | CGW | Activity, Biometrics | F, TM, RP |
| Outcome of the modified Lapidus procedure for hallux valgus deformity during the first year following surgery: A prospective clinical and gait analysis study | Moerenhout, K., et al. | 2019 | Switzerland | Original Prospective | Orthopaedics | Post | RGW | Biometrics | F, TM |
| Physical Function, Quality of Life, and Energy Expenditure During Activities of Daily Living in Obese, Post-Bariatric, and Healthy Subjects | Monteiro, F., et al. | 2017 | Brazil | Original Prospective | Bariatric | Post | RGW | Activity | F, TM, P |
Table A2. Cont.

| Title                                                                 | Author                  | Year | Country  | Study Design | Surgical Specialty | Pathway Phase | Technology Type | Data Type     | Function |
|-----------------------------------------------------------------------|-------------------------|------|----------|--------------|---------------------|---------------|----------------|---------------|----------|
| Towards a new Concept to the Neurological Recovery for Knee Stabilization after Anterior Cruciate Ligament Reconstruction Based on Surface Electrical Stimulation | Moreno, J. C., et al.  | 2008 | Spain    | Feasibility/Validity | Orthopaedics     | Post          | RGW            | Biometrics   | F        |
| Duration and frequency of every day activities in total hip patients | Morlock, M., et al.     | 2001 | Germany  | Original Prospective | Orthopaedics     | Post          | RGW            | Activity     | E, TM    |
| Physical performance in kidney transplanted patients: a study on desert trekking | Mosconi, G., et al.     | 2011 | Italy    | Original Prospective | Transplant        | Post          | RGW            | Activity, Biometrics | TM      |
| Identifying subgroups of community-dwelling older adults and their prospective associations with long-term knee osteoarthritis outcomes | Munugoda, I. P., et al. | 2020 | Australia | Original Prospective | Orthopaedics     | Pre           | CGW            | Activity     | TM, RP, P |
| High-grade rotatory knee laxity may be Predictable in ACL injuries  | Musahl, V., et al.      | 2018 | USA      | Original Prospective | Orthopaedics     | Pre           | RGW            | Biometrics   | RP, P     |
| The effect of patella resurfacing in total knee arthroplasty on functional range of movement measured by flexible electrogoniometry | Myles, C. M., et al.    | 2006 | UK       | Original Prospective | Orthopaedics     | Post          | RGW            | Biometrics   | TM, P     |
| How Many Steps Per Day are Necessary to Prevent Postoperative Complications Following Hepato-Pancreato-Biliary Surgeries for Malignancy? | Nakajima, H., et al.    | 2020 | Japan    | Original Prospective | Surgical Oncology, General Surgery | Pre    | RGW            | Activity     | RP       |
| Assessment of Early Gait Recovery After Anterior Approach Compared to Posterior Approach Total Hip Arthroplasty: A Smartphone Accelerometer-Based Study | Nelms, N. J., et al.    | 2019 | USA      | Original Prospective | Orthopaedics     | Pre, Post      | SP             | Activity, Biometrics | RP      |
| Value of the average basal daily walked distance measured using a pedometer to Predict maximum oxygen consumption per minute in patients undergoing lung resection | Novoa, N. M., et al.    | 2011 | Spain    | Original Prospective | Cardiothoracic    | Pre, Post      | CGW            | Activity     | F, P     |
| Influence of major Pulmonary resection on Postoperative daily ambulatory activity of the patients | Novoa, N., et al.       | 2009 | Spain    | Original Prospective | Cardiothoracic    | Pre, Post      | CGW            | Activity, Biometrics | P       |
Table A2. Cont.

| Title                                                                 | Author               | Year | Country | Study Design       | Surgical Specialty | Pathway Phase | Technology Type | Data Type         | Function   |
|----------------------------------------------------------------------|----------------------|------|---------|--------------------|---------------------|---------------|-----------------|------------------|------------|
| A prospective randomised double-blind study of functional outcome and range of flexion following total knee replacement with the NexGen standard and high flexion components | Nutton, R. W., et al. | 2008 | UK      | Original Prospective | Orthopaedics        | Post          | RGW             | Activity, Biometrics | TM......... |
| Does a mobile-bearing, high-flexion design increase knee flexion after total knee replacement? | Nutton, R. W., et al. | 2012 | UK      | Original Prospective | Orthopaedics        | Post          | RGW             | Biometrics        | TM.......... |
| Preoperative home-based physical therapy versus usual care to improve functional health of frail older adults scheduled for elective total hip arthroplasty: a pilot randomized controlled trial | Oosting, E., et al.  | 2012 | Netherlands | Feasibility/Validity | Orthopaedics        | Pre, Post    | CGW             | Activity          | F........... |
| Preoperative home-based physical therapy versus usual care to improve functional health of frail older adults scheduled for elective total hip arthroplasty: a pilot randomized controlled trial | Oosting, E., et al.  | 2012 | Netherlands | Feasibility/Validity | Orthopaedics        | Pre, Post    | CGW             | Activity          | F........... |
| Preoperative home-based physical therapy versus usual care to improve functional health of frail older adults scheduled for elective total hip arthroplasty: a pilot randomized controlled trial | Oosting, E., et al.  | 2012 | Netherlands | Feasibility/Validity | Orthopaedics        | Pre, Post    | CGW             | Activity          | F........... |
| Preoperative home-based physical therapy versus usual care to improve functional health of frail older adults scheduled for elective total hip arthroplasty: a pilot randomized controlled trial | Oosting, E., et al.  | 2012 | Netherlands | Feasibility/Validity | Orthopaedics        | Pre, Post    | CGW             | Activity          | F........... |
| Preoperative home-based physical therapy versus usual care to improve functional health of frail older adults scheduled for elective total hip arthroplasty: a pilot randomized controlled trial | Oosting, E., et al.  | 2012 | Netherlands | Feasibility/Validity | Orthopaedics        | Pre, Post    | CGW             | Activity          | F........... |
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| Preoperative home-based physical therapy versus usual care to improve functional health of frail older adults scheduled for elective total hip arthroplasty: a pilot randomized controlled trial | Oosting, E., et al.  | 2012 | Netherlands | Feasibility/Validity | Orthopaedics        | Pre, Post    | CGW             | Activity          | F........... |
| Preoperative home-based physical therapy versus usual care to improve functional health of frail older adults scheduled for elective total hip arthroplasty: a pilot randomized controlled trial | Oosting, E., et al.  | 2012 | Netherlands | Feasibility/Validity | Orthopaedics        | Pre, Post    | CGW             | Activity          | F........... |
| Preoperative home-based physical therapy versus usual care to improve functional health of frail older adults scheduled for elective total hip arthroplasty: a pilot randomized controlled trial | Oosting, E., et al.  | 2012 | Netherlands | Feasibility/Validity | Orthopaedics        | Pre, Post    | CGW             | Activity          | F........... |
| Preoperative home-based physical therapy versus usual care to improve functional health of frail older adults scheduled for elective total hip arthroplasty: a pilot randomized controlled trial | Oosting, E., et al.  | 2012 | Netherlands | Feasibility/Validity | Orthopaedics        | Pre, Post    | CGW             | Activity          | F........... |
| Preoperative home-based physical therapy versus usual care to improve functional health of frail older adults scheduled for elective total hip arthroplasty: a pilot randomized controlled trial | Oosting, E., et al.  | 2012 | Netherlands | Feasibility/Validity | Orthopaedics        | Pre, Post    | CGW             | Activity          | F........... |
| Preoperative home-based physical therapy versus usual care to improve functional health of frail older adults scheduled for elective total hip arthroplasty: a pilot randomized controlled trial | Oosting, E., et al.  | 2012 | Netherlands | Feasibility/Validity | Orthopaedics        | Pre, Post    | CGW             | Activity          | F........... |
| Preoperative home-based physical therapy versus usual care to improve functional health of frail older adults scheduled for elective total hip arthroplasty: a pilot randomized controlled trial | Oosting, E., et al.  | 2012 | Netherlands | Feasibility/Validity | Orthopaedics        | Pre, Post    | CGW             | Activity          | F........... |
| Preoperative home-based physical therapy versus usual care to improve functional health of frail older adults scheduled for elective total hip arthroplasty: a pilot randomized controlled trial | Oosting, E., et al.  | 2012 | Netherlands | Feasibility/Validity | Orthopaedics        | Pre, Post    | CGW             | Activity          | F........... |
| Preoperative home-based physical therapy versus usual care to improve functional health of frail older adults scheduled for elective total hip arthroplasty: a pilot randomized controlled trial | Oosting, E., et al.  | 2012 | Netherlands | Feasibility/Validity | Orthopaedics        | Pre, Post    | CGW             | Activity          | F........... |
| Preoperative home-based physical therapy versus usual care to improve functional health of frail older adults scheduled for elective total hip arthroplasty: a pilot randomized controlled trial | Oosting, E., et al.  | 2012 | Netherlands | Feasibility/Validity | Orthopaedics        | Pre, Post    | CGW             | Activity          | F........... |
| Preoperative home-based physical therapy versus usual care to improve functional health of frail older adults scheduled for elective total hip arthroplasty: a pilot randomized controlled trial | Oosting, E., et al.  | 2012 | Netherlands | Feasibility/Validity | Orthopaedics        | Pre, Post    | CGW             | Activity          | F........... |
| Preoperative home-based physical therapy versus usual care to improve functional health of frail older adults scheduled for elective total hip arthroplasty: a pilot randomized controlled trial | Oosting, E., et al.  | 2012 | Netherlands | Feasibility/Validity | Orthopaedics        | Pre, Post    | CGW             | Activity          | F........... |
| Preoperative home-based physical therapy versus usual care to improve functional health of frail older adults scheduled for elective total hip arthroplasty: a pilot randomized controlled trial | Oosting, E., et al.  | 2012 | Netherlands | Feasibility/Validity | Orthopaedics        | Pre, Post    | CGW             | Activity          | F........... |
| Preoperative home-based physical therapy versus usual care to improve functional health of frail older adults scheduled for elective total hip arthroplasty: a pilot randomized controlled trial | Oosting, E., et al.  | 2012 | Netherlands | Feasibility/Validity | Orthopaedics        | Pre, Post    | CGW             | Activity          | F........... |
| Preoperative home-based physical therapy versus usual care to improve functional health of frail older adults scheduled for elective total hip arthroplasty: a pilot randomized controlled trial | Oosting, E., et al.  | 2012 | Netherlands | Feasibility/Validity | Orthopaedics        | Pre, Post    | CGW             | Activity          | F........... |
| Preoperative home-based physical therapy versus usual care to improve functional health of frail older adults scheduled for elective total hip arthroplasty: a pilot randomized controlled trial | Oosting, E., et al.  | 2012 | Netherlands | Feasibility/Validity | Orthopaedics        | Pre, Post    | CGW             | Activity          | F........... |
| Preoperative home-based physical therapy versus usual care to improve functional health of frail older adults scheduled for elective total hip arthroplasty: a pilot randomized controlled trial | Oosting, E., et al.  | 2012 | Netherlands | Feasibility/Validity | Orthopaedics        | Pre, Post    | CGW             | Activity          | F........... |
| Preoperative home-based physical therapy versus usual care to improve functional health of frail older adults scheduled for elective total hip arthroplasty: a pilot randomized controlled trial | Oosting, E., et al.  | 2012 | Netherlands | Feasibility/Validity | Orthopaedics        | Pre, Post    | CGW             | Activity          | F........... |
| Preoperative home-based physical therapy versus usual care to improve functional health of frail older adults scheduled for elective total hip arthroplasty: a pilot randomized controlled trial | Oosting, E., et al.  | 2012 | Netherlands | Feasibility/Validity | Orthopaedics        | Pre, Post    | CGW             | Activity          | F........... |
| Preoperative home-based physical therapy versus usual care to improve functional health of frail older adults scheduled for elective total hip arthroplasty: a pilot randomized controlled trial | Oosting, E., et al.  | 2012 | Netherlands | Feasibility/Validity | Orthopaedics        | Pre, Post    | CGW             | Activity          | F........... |
| Preoperative home-based physical therapy versus usual care to improve functional health of frail older adults scheduled for elective total hip arthroplasty: a pilot randomized controlled trial | Oosting, E., et al.  | 2012 | Netherlands | Feasibility/Validity | Orthopaedics        | Pre, Post    | CGW             | Activity          | F........... |
| Preoperative home-based physical therapy versus usual care to improve functional health of frail older adults scheduled for elective total hip arthroplasty: a pilot randomized controlled trial | Oosting, E., et al.  | 2012 | Netherlands | Feasibility/Validity | Orthopaedics        | Pre, Post    | CGW             | Activity          | F........... |
| Preoperative home-based physical therapy versus usual care to improve functional health of frail older adults scheduled for elective total hip arthroplasty: a pilot randomized controlled trial | Oosting, E., et al.  | 2012 | Netherlands | Feasibility/Validity | Orthopaedics        | Pre, Post    | CGW             | Activity          | F........... |
| Preoperative home-based physical therapy versus usual care to improve functional health of frail older adults scheduled for elective total hip arthroplasty: a pilot randomized controlled trial | Oosting, E., et al.  | 2012 | Netherlands | Feasibility/Validity | Orthopaedics        | Pre, Post    | CGW             | Activity          | F........... |
| Preoperative home-based physical therapy versus usual care to improve functional health of frail older adults scheduled for elective total hip arthroplasty: a pilot randomized controlled trial | Oosting, E., et al.  | 2012 | Netherlands | Feasibility/Validity | Orthopaedics        | Pre, Post    | CGW             | Activity          | F........... |
| Title                                                                 | Author                      | Year | Country  | Study Design          | Surgical Specialty | Pathway Phase | Technology Type | Data Type          | Function |
|----------------------------------------------------------------------|-----------------------------|------|----------|-----------------------|--------------------|---------------|-----------------|-------------------|----------|
| Walking, Sedentary Time and Health-Related Quality Life Among Kidney Transplant Recipients: An Exploratory Study | Raymond, J., et al.         | 2015 | Canada   | Original Cross-sectional | Transplant         | Post          | RGW             | Activity, Biometrics | O        |
| Dual Mode Gait Sonification for Rehabilitation After Unilateral Hip Arthroplasty | Reh, J., et al.             | 2019 | Germany  | Original Prospective   | Orthopaedics       | Post          | RGW             | Activity, Biometrics | TM       |
| A prospective randomized comparison of the minimally invasive direct anterior and the transgluteal approach for primary total hip arthroplasty | Reichert, J. C., et al.     | 2018 | Germany  | Original Prospective   | Orthopaedics       | Post          | RGW             | Activity           | O        |
| Physical Activity and Sedentary Behavior in Bariatric Patients Long-Term Post-Surgery | Reid, R. E. R., et al.      | 2015 | Canada   | Original Prospective   | Bariatric          | Post          | RGW             | Activity, Biometrics | TM       |
| Physical activity levels after limb salvage surgery are not related to clinical scores-objective activity assessment in 22 patients after malignant bone tumor treatment with modular prostheses | Rosenbaum, D., et al.       | 2008 | Germany  | Original Prospective   | Orthopaedics       | Post          | RGW             | Activity           | TM       |
| Multi-segment foot kinematics after total ankle replacement and ankle arthrodesis during relatively long-distance gait | Rouhani, H., et al.         | 2012 | Switzerland | Original Prospective   | Orthopaedics       | Post          | RGW             | Biometrics         | TM, O    |
| The effect of total knee arthroplasty on joint movement during functional activities and joint range of motion with particular regard to higher flexion users | Rowe, P. J., et al.         | 2005 | UK       | Original Prospective   | Orthopaedics       | Pre, Post     | RGW             | Biometrics         | RP       |
| Energy Harvesting and Sensing with Embedded Piezoelectric Ceramics in Knee Implants | Safaei, M., et al.          | 2018 | USA      | Feasibility/Validity   | Orthopaedics       | Post          | RGW             | Activity, Biometrics | F        |
| Development and validation of a lower-extremity activity scale. Use for patients treated with revision total knee arthroplasty | Saleh, K. J., et al.        | 2005 | USA      | Feasibility/Validity   | Orthopaedics       | Post          | Unknown         | Activity           | P        |
| Initial ExPerience with Real-Time Continuous Physical Activity Monitoring in Patients Undergoing Spine Surgery | Scheer, J. K., et al.       | 2017 | USA      | Original Prospective   | Neurosurgery       | Post          | CGW             | Activity           | TM       |
| Validation of Activity Tracking Procedures in Elderly Patients after Operative Treatment of Proximal Femur Fractures | Schmal, H., et al.          | 2018 | Denmark  | Original Prospective   | Orthopaedics       | Post          | CGW             | Activity           | O        |
| Quantitative assessment of walking activity after total hip or knee replacement | Schmalzried, T. P., et al.  | 1998 | USA      | Original Prospective   | Orthopaedics       | Post          | CGW             | Activity           | TM       |
| Title | Author | Year | Country | Study Design | Surgical Specialty | Pathway Phase | Technology Type | Data Type | Function |
|-------|--------|------|---------|--------------|--------------------|---------------|----------------|-----------|----------|
| Physical activity after outpatient surgery and enhanced recovery for total knee arthroplasty | Schotanus, M. G. M., et al. | 2017 | Netherlands | Original Prospective | Orthopaedics | Post | CGW | Activity | TM, O |
| Step activity monitoring in lumbar stenosis patients undergoing decompressive surgery | Schulte, T. L., et al. | 2010 | Germany | Original Prospective | Neurosurgery | Pre, Post | RGW | Activity | TM |
| Horizontal jumping biomechanics among elite male handball players with and without anterior cruciate ligament reconstruction. An inertial sensor unit-based study | Setuain, I., et al. | 2019 | Spain | Original Prospective | Orthopaedics | Post | RGW | Biometrics | TM |
| Acceleration and Orientation Jumping Performance Differences Among Elite Professional Male Handball Players with or Without Previous ACL Reconstruction: An Inertial Sensor Unit-Based Study | Setuain, I., et al. | 2015 | Spain | Original Prospective | Orthopaedics | Post | RGW | Biometrics | TM |
| Optimal Sampling Frequency for Wearable Sensor Data in Arthroplasty Outcomes RGW. A Prospective Observational Cohort Trial | Shah, R. F., et al. | 2019 | USA | Original Prospective | Orthopaedics | Post | CGW | Biometrics | P |
| Step Activity After Surgical Treatment of Ankle Arthritis | Shofer, J. B., et al. | 2019 | USA | Original Prospective | Orthopaedics | Pre, Post | RGW | Activity | TM |
| Activity sampling in the assessment of patients with total joint arthroplasty | Silva, M., et al. | 2005 | USA | Original Prospective | Orthopaedics | Post | CGW | Activity | TM |
| Dynamic assessment of the wrist after total wrist arthroplasty | Singh, H. P., et al. | 2017 | UK | Original Prospective | Orthopaedics | Post | RGW | Biometrics | TM |
| Dynamic assessment of wrist after proximal row carpectomy and 4-corner fusion | Singh, H. P., et al. | 2014 | UK | Original Prospective | Orthopaedics | Post | RGW | Biometrics | TM |
| Comparison of the clinical and functional outcomes following 3- and 4-corner fusions | Singh, H. P., et al. | 2015 | UK | Original Prospective | Orthopaedics | Post | RGW | Biometrics | TM |
| Quantifying Real-World Upper-Limb Activity Via Patient-Initiated Movement After Nerve Reconstruction for Upper Brachial Plexus Injury | Smith, B. W., et al. | 2019 | USA | Original Prospective | Neurosurgery | Post | RGW | Activity | F |
| The effect of electromagnetic navigation in total knee arthroplasty on knee kinematics during functional activities using flexible electrogoniometry | Smith, J. R., et al. | 2013 | UK | Original Prospective | Orthopaedics | Post | RGW | Biometrics | O |
| A Randomized Study of Exercise and Fitness Trackers in Obese Patients After Total Knee Arthroplasty | Smith, W. A., et al. | 2019 | USA | Original Prospective | Orthopaedics | Post | CGW | Activity | O |
| Title | Author | Year | Country | Study Design | Surgical Specialty | Pathway Phase | Technology Type | Data Type | Function |
|-------|--------|------|---------|--------------|---------------------|--------------|----------------|-----------|----------|
| Objective measurement of function following lumbar spinal stenosis decompression reveals improved functional capacity with stagnant real-life physical activity | Smuck, M., et al. | 2018 | USA | Original Prospective | Neurosurgery | Pre, Post | RGW | Activity, Biometrics | TM |
| Preliminary evidence for physical activity following pelvic exenteration: a pilot longitudinal cohort study | Steffens, D., et al. | 2019 | Australia | Original Prospective | Surgical Oncology | Post | RGW | Activity | TM |
| A Cyber-Physical System for Near Real-Time Monitoring of At-Home Orthopedic Rehabilitation and Mobile-Based Provider-Patient Communications to Improve Adherence: Development and Formative Evaluation | Stevens, T., et al. | 2020 | USA | Feasibility/Validity | Orthopaedics | Post | SP | Activity | F |
| Reliability of the 6-min walking test Smartphone application | Stienen, M. N., et al. | 2019 | Switzerland | Feasibility/Validity | Neurosurgery | Post | SP | Activity | F |
| Wireless Monitoring Program of Patient-Centered Outcomes and Recovery Before and After Major Abdominal Cancer Surgery | Sun, V., et al. | 2017 | USA | Original Prospective | General Surgery | Pre, Post | CGW | Activity | TM |
| Clinical Evaluation of Implant-Supported Removable Partial Dentures with a Stress-Breaking Attachment | Suzuki, Y., et al. | 2017 | Japan | Original Prospective | Oromaxillofacial | Post | CGW | Biometrics | TM, O |
| A Mobile Health Application to Track Patients After Gastrointestinal Surgery: Results from a Pilot Study | Symer, M. M., et al. | 2017 | USA | Feasibility/Validity | Colorectal | Post | CGW | Biometrics | TM |
| Which functional assessments predict long-term wear after total hip arthroplasty? | Takenaga, R. K., et al. | 2013 | USA | Original Prospective | Orthopaedics | Post | RGW | Activity | P |
| Physical Behavior and Function Early After Hip Fracture Surgery in Patients Receiving Comprehensive Geriatric Care or Orthopedic Care-A Randomized Controlled Trial | Taraldsen, K., et al. | 2014 | Norway | Original Prospective | Orthopaedics | Post | RGW | Biometrics | TM, P |
| Multiple days of monitoring are needed to obtain a reliable estimate of physical activity in hip-fracture patients | Taraldsen, K., et al. | 2014 | Norway | Original Prospective | Orthopaedics | Post | RGW | Activity, Biometrics | TM, O |
| The long-term effect of being treated in a geriatric ward compared to an orthopaedic ward on six measures of free-living physical behavior 4 and 12 months after a hip fracture—a randomised controlled trial | Taraldsen, K., et al. | 2014 | Norway | Original Prospective | Orthopaedics | Post | RGW | Activity | TM |
| Title                                                                 | Author                                      | Year | Country | Study Design | Surgical Specialty | Pathway Phase | Technology Type | Data Type | Function |
|----------------------------------------------------------------------|---------------------------------------------|------|---------|--------------|---------------------|---------------|----------------|-----------|----------|
| John Charnley Award: Randomized Clinical Trial of Direct Anterior and MiniPosterior Approach THA: Which Provides Better Functional Recovery? | Taunton, M. J., et al.                     | 2018 | USA     | Original Prospective | Orthopaedics       | Post           | RGW           | Activity  | O        |
| Quantified-Self for Obesity: Physical Activity Behaviour Sensing to Improve Health Outcomes | Taylor, D., et al.                         | 2016 | UK      | Original Prospective | Bariatric           | Pre, Post      | SP            | Activity   | F, TM    |
| The Ambulatory Eye Shield Head Tracking Device with Real-Time Feedback for Gas Filled Eye Patients | Thanawattano, C., et al.                   | 2019 | Thailand| Feasibility/Validity | Ophthalmology       | Post           | SP, RGW        | Biometrics  | F        |
| Assessment of Physical Activity by Wearable Technology During Rehabilitation After Cardiac Surgery: Explorative Prospective Monocentric Observational Cohort Study | Thijs, I., et al.                          | 2019 | Belgium | Original Prospective | Cardiothoracic     | Post           | CGW           | Activity   | O        |
| Recovery of mandibular motion after closed and open treatment of unilateral mandibular condylar process fractures | Throckmorton, G. S. and E. Ellis           | 2000 | USA     | Original Prospective | Oromaxillofacial    | Post           | RGW           | Biometrics  | TM       |
| The monitoring of activity at home after total hip arthroplasty       | Toogood, P. A., et al.                     | 2016 | USA     | Original Prospective | Orthopaedics       | Post           | CGW           | Activity   | TM       |
| Normative data of a Smartphone app-based 6-min walking test, test-retest reliability, and content validity with patient-reported outcome measures | Tasic, L., et al.                          | 2020 | Switzerland | Feasibility/Validity | Neurosurgery       | Post           | SP            | Activity   | O        |
| Evaluation of improvement in quality of life and physical activity after total knee arthroplasty in greek elderly women | Tsonga, T., et al.                        | 2011 | Greece  | Original Prospective | Orthopaedics       | Post           | CGW           | Activity   | TM       |
| Tele-rehabilitation of Patients with Injuries of the Lower Extremities | Tsvyakh, A. I. and A. J. Hospodarskyy     | 2017 | Ukraine | Feasibility/Validity | Orthopaedics       | Post           | RGW           | Activity   | O        |
| Measurement of physical activity in the Pre- and early Post-operative Period after total knee arthroplasty for Osteoarthritis using a Fitbit Flex device | Twiggs, J., et al.                        | 2018 | Australia | Original Prospective | Orthopaedics       | Pre, Post      | CGW           | Activity   | TM       |
| Measuring physical activity in patients after surgery for a malignant tumour in the leg—The reliability and validity of a continuous ambulatory activity monitor | van Dam, M. S., et al.                    | 2001 | Netherlands | Feasibility/Validity | Surgical Oncology | Post           | RGW           | Activity   | TM       |
| Measuring physical activity in patients after surgery for a malignant tumour in the leg. The reliability and validity of a continuous ambulatory activity monitor | van Dam, M. S., et al.                    | 2001 | Netherlands | Original Prospective | Orthopaedics       | Post           | RGW           | Activity   | TM       |
| Title                                                                 | Author                             | Year | Country       | Study Design     | Surgical Specialty | Pathway Phase | Technology Type | Data Type    | Function |
|----------------------------------------------------------------------|------------------------------------|------|---------------|------------------|-------------------|---------------|----------------|--------------|----------|
| Fatigue, level of everyday physical activity and quality of life after liver transplantation | van den Berg-Emons, R., et al.    | 2006 | Netherlands   | Original Prospective | Transplant        | Post          | RGW            | Activity    | TM       |
| Knee kinematics in functional activities seven years after total knee arthroplasty | van der Linden, M. L., et al.     | 2006 | UK            | Original Prospective | Orthopaedics      | Post          | RGW            | Biometrics   | TM       |
| Between-day repeatability of knee kinematics during functional tasks recorded using flexible electromyography | van der Linden, M. L., et al.     | 2008 | UK            | Original Prospective | Orthopaedics      | Post          | RGW            | Biometrics   | TM       |
| Exercise therapy after coronary artery bypass graft surgery: a randomized comparison of a high and low frequency exercise therapy program | van der Peijl, I. D., et al.      | 2004 | Netherlands   | Original Prospective | Cardiothoracic    | Post          | RGW            | Activity    | RP       |
| Feedback From Activity Trackers Improves Daily Step Count After Knee and Hip Arthroplasty: A Randomized Controlled Trial | Van der Walt, N., et al.          | 2018 | Australia     | Original Prospective | Orthopaedics      | Pre, Post     | CGW            | Activity    | O        |
| Validation of a novel activity monitor in impaired, slow-walking, crutch-supported patients | van Laarhoven, S. N., et al.      | 2016 | Netherlands   | Feasibility/Validity | Orthopaedics      | Post          | CGW            | Activity    | F        |
| Individual Patient-reported Activity Levels Before and After Joint Arthroplasty Are Neither Accurate nor Reproducible | Vaughn, N. H., et al.             | 2019 | USA           | Original Prospective | Orthopaedics      | Post          | CGW            | Activity    | TM       |
| A kinematical analysis of the shoulder after arthroplasty during a hair combing task | Veeger, H. E., et al.             | 2006 | Netherlands   | Original Prospective | Orthopaedics      | Post          | RGW            | Biometrics   | P        |
| Grammont versus laterализing reverse shoulder arthroplasty for proximal humerus fracture: functional and radiographic outcomes | Verdano, M. A., et al.           | 2018 | Italy         | Original Retrospective | Orthopaedics      | Post          | RGW            | Biometrics   | O        |
| Walking and chair rising performed in the daily life situation before and after total hip arthroplasty | Vissers, M. M., et al.            | 2011 | Netherlands   | Original Prospective | Orthopaedics      | Pre, Post     | RGW            | Activity    | TM       |
| Functional capacity and actual daily activity do not contribute to patient satisfaction after total knee arthroplasty | Vissers, M. M., et al.            | 2010 | Netherlands   | Original Prospective | Orthopaedics      | Pre, Post     | RGW            | Activity    | O        |
| Function and activity after minimally invasive total hip arthroplasty compared to a healthy population | von Rottkay, E., et al.           | 2018 | Germany       | Original Prospective | Orthopaedics      | Post          | RGW            | Activity    | TM       |
| Title                                                                 | Author             | Year | Country | Study Design | Surgical Specialty | Pathway Phase | Technology Type | Data Type       | Function |
|----------------------------------------------------------------------|--------------------|------|---------|--------------|-------------------|---------------|----------------|-----------------|----------|
| Wearable Sensor-Based Digital Biomarker to Estimate Chest Expansion During Sit-to-Stand Transitions—A Practical Tool to Improve Sternal Precautions in Patients Undergoing Median Sternotomy | Wang, C., et al.   | 2019 | USA     | Feasibility/Validity | Cardiothoracic | Post          | RGW            | Biometrics      | F        |
| Quantifying the influence of DBS surgery in patients with Parkinson’s disease during Perioperative Period by wearable sensors | Wang, J., et al.   | 2019 | China   | Original Prospective     | Neurosurgery  | Pre, Peri, Post | RGW            | Biometrics      | TM       |
| Upper extremity function in the free living environment of adults with traumatic brachial plexus injuries | Webber, C. M., et al. | 2019 | USA     | Original Prospective     | Orthopaedics  | Pre, Post      | RGW            | Activity, Biometrics | TM       |
| Sedentary Behavior, Cadence, and Physical Activity Outcomes after Knee Arthroplasty | Webber, S. C., et al. | 2017 | Canada  | Original Prospective     | Orthopaedics  | Post          | RGW            | Activity        | TM, RP   |
| Use of Activity Tracking in Major Visceral Surgerythe Enhanced Perioperative Mobilization Trial: a Randomized Controlled Trial | Wolk, S., et al.   | 2017 | Germany | Original Prospective     | General Surgery | Post         | CGW            | Activity        | F        |
| Wearable-Based Mobile Health App in Gastric Cancer Patients for Postoperative Physical Activity Monitoring, Focus Group Study | Wu, J. M., et al.  | 2019 | Taiwan  | Feasibility/Validity     | Surgical Oncology | Pre, Peri, Post | SP             | Activity        | F        |
| Assessing function in patients undergoing joint replacement: a study protocol for a cohort study | Wylde, V., et al.  | 2012 | UK      | Original Prospective     | Orthopaedics  | Post          | RGW            | Activity        | TM       |
| Implantable Multi-Modality Probe for Subdural Simultaneous Measurement of Electrophysiology, Hemodynamics, and Temperature Distribution | Yamakawa, T., et al. | 2019 | Japan   | Feasibility/Validity     | Neurosurgery  | Peri, Post     | RGW            | Biometrics      | F        |
| Sensor-Based Upper-Extremity Frailty Assessment for the Vascular Risk Stratification | Yanquez, F. J., et al. | 2020 | USA     | Feasibility/Validity     | Vascular      | Post          | RGW            | Biometrics      | RP       |
| Kinematic study of the temporomandibular joint in normal subjects and patients following unilateral temporomandibular joint arthroplasty with metal fossa-eminence partial joint replacement | Yoon, H. J., et al. | 2007 | South Korea | Original Prospective     | Oromaxillofacial | Post         | SP, CGW        | Biometrics      | TM       |
| Biomechanical Gait Variable Estimation Using Wearable Sensors after Unilateral Total Knee Arthroplasty | Youn, I. H., et al. | 2018 | South Korea | Feasibility/Validity     | Orthopaedics  | Post          | RGW            | Biometrics      | F        |
| Title | Author | Year | Country | Study Design | Surgical Specialty | Pathway Phase | Technology Type | Data Type | Function |
|-------|--------|------|---------|--------------|-------------------|---------------|----------------|-----------|----------|
| Over-the-top ACL Reconstruction Plus Extra-articular Lateral Tenodesis with Hamstring Tendon Grafts: Prospective Evaluation with 20-Year Minimum Follow-up | Zafragnini, S., et al. | 2017 | Italy | Original Prospective | Orthopaedics | Post | RGW | Biometrics | TM |
| Assessing activity in joint replacement patients | Zahiri, C. A., et al. | 1998 | USA | Original Prospective | Orthopaedics | Post | Unknown | Activity | TM |
| Evaluation of Gait Variable Change over Time as Transtibial Amputees Adapt to a New Prosthesis Foot | Zhang, X., et al. | 2019 | China | Original Prospective | Orthopaedics | Post | RGW | Biometrics | TM |

CGW = Consumer-Grade Wearables, RGW = Research-Grade Wearables, SP = Smartphone, F = Feasibility, TM = Tracking or Monitoring, RP = Risk Profiling, O = Optimization, P = Prediction.

Appendix D

| Table A3. List of Surgical Specialties and Procedures. |
|------------------------------------------------------|
| **Bariatric Surgery** |
| Gastric Bypass Surgery |
| **Breast Surgery** |
| Mastectomy |
| Breast Cancer Surgery |
| **Cardiothoracic Surgery** |
| Angioplasty |
| Arterial Catheterization |
| Cardiac Surgery |
| Coronary Artery Bypass Grafting |
| Elective Cardiac Surgery |
| Pulmonary Surgery |
| Lung Cancer Surgery |
| Lung Lobectomy |
| Lung Resection |
| **Major Pulmonary Surgery** |
| Sternotomy |
| Thoracic Surgery |
| **Colorectal Surgery** |
| **General Surgery** |
| Obstetrics and Gynecology |
| Cesarian Section |
| Hysterectomy |
| **Ophthalmologic Surgery** |
| Cataract Surgery |
| Eye Surgery |
| **Oromaxillofacial Surgery** |
| Dental Implantation Surgery |
| Temporomandibular Joint Replacement |
| Unilateral Mandibular Condylar Fixation |
| **Orthopedic Surgery** |
| 3-Corner-Fusion |
| 4-Corner Fusion |
| Achilles Tendon Rupture Repair |
| ACL Reconstruction Surgery |
| Ankle Surgery |
| Back Surgery |
| Carpal Tunnel Release |
| Decompressive Spine Surgery |
| **Menisectomy** |
| Proximal Femur Fracture Fixation |
| Proximal Row Carpectomy |
| Transtibial Amputation |
| Rotator Cuff Repair |
| Shoulder Surgery |
| Shoulder Arthroplasty |
| Shoulder Prostheses Surgery |
| Spinal Stenosis Surgery |
| Spine Surgery |
| **Surgical Oncology** |
| Total Ankle Arthroplasty |
| Total Hip Arthroplasty |
| Total Joint Arthroplasty |
| Total Knee Arthroplasty |
| **Vertebroplasty** |
| Abdominal Cancer Resection |
| Major Oncologic Surgery |
| Pelvic Exenteration |
### Table A3. Cont.

| Abdominal Surgery | Fracture Repair | Sarcoma Resection |
|-------------------|----------------|------------------|
| Gastric Resection Surgery | Hallux Valgus Correction Surgery | Lower Extremity Tumor Resection |
| Gastrointestinal Resection | Hip Fracture Surgery | Transplant Surgery |
| Hepatic Resection | Hip Surgery | Elective Organ Transplantation |
| Hepatobiliopancreatic Resection | Knee Prostheses Surgery | Kidney Transplant Surgery |
| Inguinal Surgery | Limb Salvage Surgery | Liver Transplant Surgery |
| Major Abdominal Surgery | Lower Extremity Orthopedic Surgery | Urologic Surgery |
| Neurosurgery | Lower Limb Amputation Surgery | Cystectomy |
| Brachial Plexus Nerve Transfer Surgery | Lumbar Decompression Surgery | Vascular Surgery |
| Deep Brain Stimulation | Lumbar Microdiscectomy | Lower Limb Amputation Surgery |
| Transsphenoidal Surgery | Lumbar Spine Surgery | |
| Traumatic Brachial Plexus Injury Repair | Malleolar Fracture Fixation | |

### Appendix E

#### Table A4. Technologies including Activity Trackers, Smartphone Applications, Research-/Commercial-grade wearables, Other Sensors.

| Research-Grade Wearables and Sensors | Activity Tracker/Monitor (Other) | Sports Pedometers |
|--------------------------------------|---------------------------------|-------------------|
| Actigraph AM7/164-2.2 activity monitor | Apple Watch | Sportline 345 Pedometer |
| Actigraph GT1M accelerometer | Activity AX3 | Sportline Pedometer |
| ActiGraph GT3X+ Activity Monitors | Biopotential Tracking Device | SW200 Yamax Digiwalker Pedometer |
| ActiGraph wGT3X-BT accelerometer | BioPAC Tracking Device | USB Accelerometer ModelX8M |
| ActiVision activity monitor | Digi-Walker SW-200 Pedometer | USB accelerometer X16 mini |
| ADXL 210 accelerometers | Fitbase | Visual Behavior Monitor |
| ADXRS 250 gyroscopes | Fitbit | Wavelet Health Wristband |
| AMP-331c Activity Monitor | Fitbit Charge | Withings Pulse Ox Activity Monitor |
| Analog Devices accelerometer | Fitbit Flex | Yamax FitPro Pedometer |
| APDM Movement Monitoring System | Fitbit Zip | Yamax SW 200/LS2000 Pedometer |
| Biometrics XM65 Electrogoniometer | Fitness Tracker (Other) | Smartphone Applications |
| BioSensics Triaxial Gyroscope Sensors | Garmin (Other) | 6WT Application |
| BioStampRC Sensors | Garmin Vivoactive HR device | Beise Application |
| Dynaport ADL monitor | Garmin VivoFit2 | Capstesia Application |
| Electrogoniometer (Other) | GC Dataconcepts LLC Accelerometer | mHealth Application |
| Exfix Accelerometer | Activity Monitor | Moves Application by Protageo |
| Flock of Birds | HITEC Pedometer | POHTRACK (Postoperative Head Tracking Device) Application |
| Footswitches | Lumo Lift Device | Rehabilitation Monitoring Application |
| SG150 Flexible Electrogoniometer | Lumo Run | Smartphone accelerometer |
| SHIMMER 2R Sensor Units | MetaWear C Sensor Board | |
| GT9X Link ActiGraph | ShoWider | MiBand2 | Spine-Specific 6WT Application |
|---------------------|----------|---------|-------------------------------|
| GWalk Sensor        | Sirognathograph by Siemens Corp | Microsoft Kinect v2 sensor | Surgery Diary Application     |
| Gyroscope (Other)   | StepWatch 3™ Activity Monitor | Mio Activity Tracker (Other) | The Motion-Monitor            |
| HipGuard            | Temec Instruments Accelerometer | Misfit Shine                  | The NeuroPath Application     |
| IC-3031 Uniaxial Piezo-resistive Accelerometers | The HealthPatch MD | New Lifestyles NL-800 Pedometer | The RehabTracker Application |
| Inclination Sensors (Other) | The PAM | Omron HJ-321-E Pedometer | TKR Application                |
| Inertial Measurement Unit | The Wake Forest RTLS | Omron HJ-720 TE2 Pedometer | WalkOn Application            |
| Intelligent Device for Energy Expenditure and Activity | Vitaport3 accelerometer | Omron Pedometer                | **Unknown**                    |
| Kenz Lifecoder GS Accelerometer | **Consumer-Grade Wearables** | Physilog®® activity monitor | Pedometer (other)             |
| KiRA                | 3Space Fastrak System | Power Walker EX-510 Yamax Step Counter |                                    |
| Lifecoder EX Pedometer | Activ8™ Professional Activity Monitor | Smartwatch (Other)           |                                    |
| M180 Electrogoniometer |                                    |                                |                                    |
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